RUNNING HEAD: REPETITION EFFECTS

Inhibitory and facilitatory effects on the perception of repeatedly presented stimuli

Kin Fai Ellick, Wong
Department of Psychology, The Chinese University of Hong Kong

A thesis submitted to Department of Psychology, The Chinese University of Hong Kong, in partial fulfillment for the degree of Master of Philosophy in Psychology

June, 1997

Acknowledgments

This research was supported by Earmarked Grants from the Research Grants Council of Hong Kong to Hsuan-Chih Chen.

I would like to express my deepest gratitude to Prof. Hsuan-Chih Chen, my thesis supervisor, for his guidance and valuable comments on this work.

I am also grateful to Dorus Chan, Nga Yan Chan, Angela Wong and Sum Yin Wong for research assistance, and to Mr. Chiu Chi Chau for technical assistance.

Thanks also go to all the voluntary participants who participated in the experiments reported in this study. I would like to express my deepest gratefulness to all people who have cared for and been concerned about the progress of my work.

Abstract

Repetition blindness (RB) refers to the failure to detect or recall repetitions of words in rapid serial visual presentation (RSVP). Experiment 1 showed that RB can be replicated with Chinese characters. Experiment 2 adopted a category monitoring task and showed that the response times to the second repeated targets were longer than the response times to the second unrepeated targets when the presentation rate was relatively fast (i.e., 117 ms/item), whereas the opposite was true when the presentation rate was relatively slow (i.e., 200 ms/item). The results of Experiment 2 were replicated in Experiment 3 in which only two critical items were presented in each trial. Experiment 4 showed that RB changed to repetition priming when the first critical items were not necessary to be responded to. Experiments 5 and 6 showed that discriminability between the two critical targets did not significantly affect the effect size of RB. Experiment 6 further showed that RB in terms of reaction times was observed in high frequency pairs only. The RB observed in the present study did not likely occur at storage or retrieval stages of operations. In addition, the reaction time data indicate that RB is not an all-or-none phenomenon. The relationship between RB and repetition priming and other methodological concerns are also discussed.

When one item is presented twice, the processing of the second one is usually affected by the presence of the first one. This so called *repetition effect* has widely been studied by cognitive psychologists for the understanding of mental structure and operations. Conventionally, psychologists paid much attention to the positive side of the repetition effect, repetition priming. It was called the positive side because processing of the repeated item benefited from the presentation of the first item in terms of processing time or accuracy. Repetition priming is a robust phenomenon that has been demonstrated across different experimental paradigms such as lexical decision (Forbach, Stanners, & Hochhaus, 1974; Scarborough, Cortese, & Scarborough, 1977; Scarborough, Gerard, & Cortese, 1979, 1984), naming (Feustel, Shiffrin, & Salasoo, 1983; Scarborough et al., 1979), and masked priming paradigm (Evett & Humphreys, 1981; Forster & Davis, 1984; Humphreys, Besner, & Quinlan, 1988).

However, facilitation is just one of the consequences of the repetition effect. In contrary to repetition priming, Kanwisher (1987) showed that in some conditions, the facilitatory repetition priming changed to inhibitory *repetition blindness*, the negative side of the repetition effect[1]. Repetition blindness (RB) refers to the phenomenon that when items are presented under rapid serial visual presentation (RSVP), lists with repeated items (e.g. A *B* C *B* D) are reported less accurately than lists without repeated items (e.g. A *E* C *B* D) (Kanwisher, 1987, 1991; Kanwisher & Potter, 1989, 1990). Recently, RB was extended to a non-RSVP paradigm in which only two critical items were presented (Hochhaus & Marohn, 1991; Luo & Caramazza, 1995; Kanwisher, Driver, & MacHado, 1995).

---

[1] Apart from RB, the negative side of the repetition effect also includes *negative priming* (See Fox, 1995; May, Kane, & Hasher, 1995 for reviews of negative priming).

The present study aims to investigate this phenomenon. This article is organized into two main parts. The first part is a general review of RB literature in past ten years. The literature review involves three sections. The first section is the discussion of the variations on the RB procedure. The second section is a review of some determinants of RB. The third section discusses the theoretical accounts of RB. After reviewing the RB literature, it turns to the second part which is the report of a series of experiments examining RB.

Variations on the RB Procedure

Repetition Blindness under RSVP

RB was originally demonstrated by Kanwisher (1987) using the RSVP paradigm, which has been the most widely adopted procedure for RB studies (Armstrong & Mewhort, 1995; Bavelier, 1994; Bavelier & Potter, 1992; Fagot & Pashler, 1995; Kanwisher, 1987, 1991; Kanwisher & Potter, 1989; 1990; MacKay & M. Miller, 1994; Whittlesea, Dorken & Podrouzek, 1995; Whittlesea & Podrouzek, 1995). The typical procedure is that a list of items is presented sequentially in the same position on the computer screen. The number of items may vary from 3 to 10 and the presentation rate may approximately vary from 34 ms per item to 150 ms per item according to the manipulations of the researchers. Participants are usually required to memorize all items in a given list and then recall verbally or write down all items immediately after the presentation is completed (Bavelier & Potter, 1992; Kanwisher, 1987; Kanwisher & Potter, 1990; MacKay & M. Miller, 1994). Under such conditions, performance (assessed by recall rates, RB index or sensitivity; see the *Measurements of RB*) on lists with repeated items is poorer than those without repeated items. For example, Bavelier and Potter (1992) found that when RSVP lists consisting of mixtures of English letters and symbols were presented and participants had to report all letters they saw after the presentation, lists with repeated letters (e.g., + = *a* c *a* &) were reported less accurately than lists without repeated letters (e.g., + = *b* c *a* &).

RB observed in RSVP paradigm is a robust effect that can be observed across a variety of stimuli and across different methods of presentation. Such robustness was well indicated in the following ways. First, the second critical items (C2s)[2] were less likely to be reported in repeated condition relative to unrepeated condition even under situations in which the encouragement of the report of the second repeated items were supposed. Kanwisher & Potter (1990), for example, presented RSVP lists containing letters which were in the order of English words (e.g., M *A* N *A* G E R). However, participants would more likely fail to report the second repeated letters (e.g., M *A* N G E R). Similarly, when sentences were presented word by word under RSVP, recall rates were poorer for sentences with repeated words (e.g., When she spilled the *ink* there was *ink* all over.) than sentences without repeated words (e.g., When she spilled the *liquid* there was *ink* all over.), even though the omission of C2 may violate the grammatical structure of the sentences (Kanwisher, 1987).

Second, RB is not restricted to letters or word pairs. RB can also be observed in digit pairs such as *8-8* (Bavelier & Potter, 1992), visual feature such as color (Kanwisher, 1991), or pictures (Bavelier, 1994). In addition, RB is not restricted to identical pairs in that orthographic overlapping or phonological overlapping (Bavelier

---

[2] C1 refers to the first critical item and C2 refers to the second one in an RSVP list. For example, in a sentence list with repeated item: "When she spilled the *ink* there was *ink* all over", the first *ink* is C1 and the second *ink* is C2. in an unrepeated control sentence: "When she spilled the *liquid* there was *ink* all over", *liquid* is C1 and *ink* is C2.

et al., 1994) is sufficient for the occurrence of RB (see the section *Manipulations of the relationship between C1 and C2*).

Finally, RB could be observed when two critical items were presented in different locations. Typically, items presented by RSVP are at the same location. However, RB also occurred when RSVP items were presented from left to right or when the first half and the second half of the lists were presented at different locations, although the RB effect of this latter condition was diminished relative to the condition that all items were presented at the same location (Kanwisher & Potter, 1989).

Therefore, RSVP paradigm, by which RB can be observed in different types of items and through different methods of presentation, is a sensitive procedure for the occurrence of RB. Furthermore, since sentences can be presented in the RSVP paradigm, it has, up to now, been the only paradigm used to investigate contextual and syntactic effects on RB (e.g., Abram, Dyer & MacKay, 1996).

Nevertheless, there are some limitations of the conventional RSVP recall paradigm. First, it usually requires participants to give a whole report of a list. Such a procedure induces a high memory demand for participants and hence one cannot be clear whether RB is the result of high memory demand or perceptual failure. Second, even though some researchers adopted a partial report rather than a whole report procedure (Armstrong & Mewhort, 1995; Fagot & Pashler, 1995; Park & Kanwisher, 1994a), responses have to be made after the presentation of a given list. Thus, it cannot be clear whether the post-list performance reflects the effects before, at, or after the presentation of the critical target words, or a mixture of all of these. Such limitations make one hard to conclude whether RB occurs at encoding or retrieval stages of operation. These encoding versus retrieval debates will be discussed in the section

Theoretical Accounts of RB.

RB observed in the two-item paradigm

Rather than presenting the two critical items embedded in other irrelevant items, some researchers present only two items to investigate RB. The repetition blindness effect found in the two-item paradigm was first accidentally demonstrated by Humphreys, Besner and Quinlan (1988) in an unmasked repetition task. In one of their experiments, primes were presented for 300ms, then targets were presented very briefly (i.e., 35 ms or 65 ms) followed by a pattern mask. Participants were asked to identify the target words. It was found that the percentages of correct target identification were lower when primes were identical to targets than when the primes were unrelated word controls. However, they also observed repetition priming (facilitation) when the primes were presented very briefly or masked.

Hochhaus and Marohn (1991) also obtained similar results with a similar procedure. They presented the priming word for a longer duration whereas the target word was presented very briefly (i.e., 16 or 32 ms). Participants had to identify the target words. When the exposure duration of the priming word was 500 ms and the target appeared immediately after the prime, RB was observed. However, when the exposure duration of the prime was shortened to 250 ms, repetition priming was observed.

Although the RSVP paradigm is the conventional procedure for RB research, it is believed that more and more researchers may use the two-item paradigm to investiage RB in the future. One of the advantages of the two-item paradigm is its low memory demand for participants. Furthermore, since the procedures and conditions in which RB was found in the two-item paradigm are similar to those for repetition priming in many important ways (e.g., Evett & Humphreys, 1981; Forster & Davis, 1984; Humphreys et al., 1988), this paradigm has the potential for researchers to understand the relationship between RB and repetition priming and more general human cognitive processing. In fact, more researchers have adopted the two-item paradigm to investigate RB recently, although the detailed procedures may vary. For example, Luo and Caramazza (1995) found RB when both a briefly presented prime and target are required to be reported. Similarly, Kanwisher, Driver and MacHado (1995) observed spatial RB when two stimuli are simultaneously presented at different locations.

Unlike the RSVP paradigm which has been used with many different manipulations between C1 and C2 (see the section on *Manipulations of the Relationship Between C1 and C2*), the two-item paradigm, to my knowledge, has only been used to investigate RB between two identical items. There is much room for more manipulations in future research using the two-item paradigm, especially given that there is no empirical evidence directly supporting or rejecting the idea that RB found in RSVP paradigm is the same as that found in two-item paradigm. Converging evidence from different tasks is very important for understanding the general mechanisms of RB and avoiding explanations that is task specific.

Manipulations of the relationship between C1 and C2

Initially, RB was found when C1 and C2 were identical (Kanwisher,1987). Then, many RB investigations in the RSVP paradigm still maintained that C1 and C2 were identical (Armstrong & Mewhort, 1995; Fagot & Pashler, 1995; Kanwisher et al. 1996; Park and Kanwisher, 1994) and in the two-item paradigm (Hochhaus & Marohn, 1991;

Luo and Caramazza, 1995; Kanwisher et al., 1995). In most, when C1 is exactly identical to C2, they share the same orthography, phonology, lexical unit and semantic unit (e.g., When she spilled the *ink* there was *ink* all over.). However, in some cases, such as homonyms (e.g., *the rose, she rose*) and homographs (e.g., *he wound, the wound*), although C1 and C2 have the same spelling, they do not share all properties. Kanwisher and Potter (1991) embedded the homonym and homograph word pairs in RSVP sentence lists and observed that RB still occurred. In other cases, although C1 and C2 are different graphemically, they share all other properties. For example, Bavelier and Potter (1992) found RB for English letter pairs with different cases (e.g., a-A), and digits with different formats (e.g., 8-eight). The priming and target words used by Humphreys et al. (1988) were also different in cases (e.g., rush-RUSH).

Furthermore, RB was found when C1 and C2 share phonological information such as *ate* and *eight* (Bavelier & Potter, 1992; Bavelier et al., 1994), semantic information such as *gusta* (a Spanish word, translation equivalent to *like* in English) and *like* (MacKay & M. Miller, 1994; but see Altarriba & Soltano, 1996), or when all items were presented auditorally (M. Miller & MacKay, 1994; but see Kanwisher & Potter, 1990). All of these findings suggest that RB seems to occur at a higher or more central level of processing rather than at the level of sensory registration, or feature analysis.

Measurements of RB

In general, RB is measured as the difference in correct (or incorrect) recall percentages of both C1 and C2 between the repeated and unrepeated condition. However, Park and Kanwisher (1994a) expressed a concern about whether this difference score is the best measurement to compare RB across conditions when the performance in unrepeated control conditions varied a lot. They reasoned that in an extreme case in which the performance of the repeated and unrepeated conditions is 70% and 90%, respectively in one level of a variable, and it is 20% and 40% respectively in another level, although the differences in these two levels are the same (i.e., 20% difference), intuition suggests that the effect of RB is larger in the second level of that variable, and hence they proposed that RB assessed by the ratio of repeated and unrepeated performance is more appropriate. Therefore, they suggested an index called repetition blindness index (RBI) to measure the effect of RB that is "simply the percentage of trials in which both critical items are reported correctly in the repeated condition, divided by the sum of the percentages of trials in which both critical items are reported correctly from the repeated and unrepeated conditions" (p. 506). However, RBI has not yet caught much attention and most RB research still measures RB as the difference in performance between repeated and unrepeated conditions.

Recently, more and more researchers (e.g., Fagot & Pashler, 1995; Hochhaus & Johnston, 1996; Kanwisher et al., 1996; Park and Kanwisher, 1994) measure RB by signal detection methods which can assess the sensitivity of discriminating two signals by eliminating the response bias. However, different measurements of sensitivity (e.g., Ag, Gaussian *d'*, High-threshold alpha), which hold different theoretical assumptions, were adopted by different researchers, although they usually provide similar patterns of results (Kanwisher et al., 1996).

Surprisingly, RB was rarely measured in terms of reaction time. To my knowledge, only one RB-related experiment (Whittlesea et al., 1995, Experiment 3a-3d), which was intended to observe repetition priming rather than RB, collected reaction times. Reaction time is widely regarded as the primary means for inference and understanding of the general structure and processes of mental systems (see Liu, 1996; Miller, 1993 for discussions about reaction time models). Reaction time data are, therefore, important for researchers to understand the full picture of RB. In particular, the reaction times of the repeated items are the critical information reflecting whether the processing of the successfully reported repeated items is different from that of the successfully reported unrepeated items. More importantly, the reaction time data can be used to infer how the successfully reported repeated items are processed. In this thesis, I will collect reaction time data by modifying the RSVP and two-item paradigm to investigate RB.

Determinants of RB

In some conditions, the effect size of RB is found to be relatively greater, whereas the effect size of RB is found to be lesser in other conditions if it does not disappear. Researchers are intereseted to find out conditions which can generate RB for the understanding of the underlying mechanism of RB. In this section, some identified determinants of RB are reviewed. Table 1 is the summary of some factors of RB in RSVP and two-item paradigms discussed in this section.

Table 1

Summary of some factors affecting RB in RSVP and two-item paradigms

Authors	Paradigms	Factors	Outcome
Bavelier (1994)	RSVP	Emphasis of visual code	RB for picture-word pairs was eliminated in task emphasis the use of visual code
Bavelier and Potter (1992)	RSVP	Effects of written format of digits on sentence lists or in lists consisting of unrelated items.	Effect size of RB was smaller for digit pairs with different formats in lists consisting of unrelated item. Effect size of RB was not affected by written format in sentence lists
Bavelier et al. (1994)	RSVP	Word frequency of critical items	Frequency did not affect RB
Kanwisher (1987, Exp. 2)	RSVP	Presentation rate	RB diminished as presentation rate decreased
Kanwisher (1987, Exp. 3)	RSVP	Whether C1 was necessary to be reported	RB changed to repetition priming when C1 was not necessary to be reported
Kanwisher (1991, Exp. 6)	RSVP	Whether C1 should be attended to	RB was not observed when C1 was not necessary to be attended to
Kanwisher and Potter (1990, Exp. 6)	RSVP	Whether C1 was necessary to be reported	RB was observed when C1 was not necessary to be reported
Kanwisher et al. (1996)	RSVP	Lag (intervening items)	RB diminished as lag increased
Park and Kanwisher (1994a, Exp. 1)	RSVP	Recognition difficulty/Presentat ion rate	RB was dependent on presentation rate but not recognition difficulty
Park and Kanwisher (1994a, Exp. 2)	RSVP	Salient of C1 and C2	RB decreased as exposure duration of C2 increased. RB did not increased as exposure duration of C1 increased
Park and Kanwisher (1994a, Exp. 3)	RSVP	Discriminability between C1 and C2	RB was not affected by whether C1 and C2 were intervened by blank interval or symbols
Hochhaus & Marohn (1991, Exp.1)	Two-item	SOA	Repetition priming was observed in 250 ms SOA, RB was observed in 500 ms SOA, no effect was observed in 750 ms or 200 ms SOA

Table 1 (*Continued*)

Authors	Paradigms	Factors	Outcome
Hochhaus & Mihura (1992, cited in Bavelier et al., 1994)	Two-item	Word frequency of critical items	RB was found only in low frequency pairs
Humphreys et al. (1988)	Two-item	Lag (trails)	RB was observed in Lag 0, and repetition priming was observed in Lag 7 condition
Humphreys et al. (1988, Exp. 4)	Two-item	Discriminability between C1 and C2	RB changed to repetition priming when C1 and C2 were intervened by a mask
Luo and Caramazza (1995)	Two-item	ISI	RB increased as ISI decreased
Luo and Caramazza (1995)	Two-item	Encoding effectiveness of C1	RB increased as exposure duration of C1 increased, and RB was observed even when C1 was not necessary to be reported
Luo and Caramazza (1996)	Two-item	Lag (intervening items)	RB diminished as lag increased
Kanwisher (1995)	Two-item (simultaneously)	Whether RB occurred in unattended dimension	RB was observed in the attended dimension only.
Luo and Caramazza (1996)	Many-item (simultaneously)	Lag (intervening items)	RB increased from Lag 0 to Lag1, then it dropped from Lag 2 to Lag 3.

Presentation Rate and Lag

In general, RB diminished under slower presentation rates (Kanwisher, 1987). Park and Kanwisher (1994a) speculated that RB could be due to recognition difficulty in fast presentation rates, or it could be due to the absolute presentation rate which is independent of recognition difficulty. In order to find out by which factors RB is determined, Park and Kanwisher matched the overall performance of a fast presentation rate (120 ms/item) to performance in a slow condition (250 ms/item) by reducing the display brightness such that performance in the unrepeated condition under slow dim presentation was equivalent to that under fast bright presentation. They found that there was no RB in the slow dim condition, thus indicating that RB is dependent on the absolute presentation rate rather than the difficulty in perceiving individual items.

The lag between C1 and C2 is also crucial to the occurrence of RB such that the effect of RB diminishes as lag increases (Luo & Caramazza, 1996; Kanwisher et al., 1996). Lag usually refers to the number of intervening items between C1 and C2 in RSVP paradigm (Kanwisher et al., 1996; Park & Kanwisher, 1994a). In this case, lag is equivalent to the stimulus onset asynchrony (SOA) between C1 and C2 when the presentation rate is constant for each item in each RSVP list. Consistently, Hochhaus & Marohn (1991) showed that RB was eliminated in the two-item paradigm when SOA was extended from 500 ms to 750 ms or 2000 ms. Luo and Caramazza (1995) also found that the effect size of RB increased as the inter-stimulus interval (ISI) between C1 and C2 decreased. Lag sometimes also refers to the number of trails intervened between prime and target. Humphreys et al. (1988) demonstrated that RB when prime and target were in the same trail, whereas repetition priming was observed when prime and target were separated by seven trials.

Luo and Caramazza (1996) argued that the critical determinant of RB is not the physical onset asynchrony between the two critical items, rather RB is determined by the coding onset asynchrony (COA) between C1 and C2. They presented 5 items simultaneously along the edge in a circle and participants were asked to report all items serially in clockwise order. In this case, the physical onset asynchrony should be zero, but they showed that the effect of RB is an inverted U-shaped function of repetition lag. The effect of RB first increased from Lag 0 to Lag 1 and dropped again from Lag 2 to

Lag 3. They attributed the U-shaped function to the refractoriness of perceptual recognition units (see the Theoretical Accounts of RB).

All of the above findings suggest that RB is sensitive to the onset asynchrony of the processing between C1 and C2 that RB decreases in size as C1 and C2 increase in temporal proximity.

Nature of task

The nature of task is an important determinant for the occurrence of RB. One of issues that has caught much attention from researchers is whether C1 has to be reported. In a very early study, Kanwisher (1987, Experiment 3) asked participants to name the last word in a given RSVP list. In this case, C1 is not necessary to be reported and only C2 must be reported. When a list consists of a word that is identical to the last word, repetition priming rather than RB was observed. However, in a very similar procedure, Kanwisher and Potter (1990) failed to replicate the above result and RB was observed instead. Furthermore, Luo and Caramazza (1995) also observed RB rather than repetition priming in the two-item paradigm when C1 was not required to be reported. Therefore, there is no consistent evidence indicating whether RB changes to repetition priming or not when C1 is not necessary to be reported. More systematic investigation is needed to give a full picture about this.

Items embedded in lists with unrelated items or embedded in lists with items forming sentences produce slightly different effects on RB. When RSVP lists consist of unrelated items, the effect size of RB was smaller for digit pairs with different written formats (e.g., *9-nine*) than those with the same format (e.g., *9-9*). However, when sentence lists were presented, the same effect size was observed for same or different formats (Bavelier & Potter, 1992). These results imply that when the task emphasizes semantic components such as sentence lists, graphemic variation play a less important role in RB. In concordance with the previous results, RB can be eliminated for picture-word pairs when the task emphasizes the use of visual codes. Bavelier (1994) observed that reliable RB occurred when participants only had to report the name of RSVP lists containing a mixture of pictures and words, but not when both the names and corresponding formats had to be reported. These studies indicate that different patterns of RB are observed due to different task demands

Distinctiveness and discriminability

The distinctiveness of C1 is an important determinant for the occurrence of RB in the two-item paradigm. Recall the results obtained by Humphreys et al. (1988) and Hochhaus and Marohn (1991). Both of them found RB only when the priming words were exposed for a relatively longer duration. When the exposure duration of the priming words were shortened, repetition priming rather than RB was observed. These results seem to suggest that the more distinctive C1 is, the more RB is found. Consistent with such a claim, Luo and Caramazza (1995) found a significant interaction between exposure duration of C1 and repetition status. In the other words, the effect size of RB increases as the exposure duration of C1 increases.

However, the RSVP paradigm seems to tell us a different story. Park and Kanwisher (1994a) doubled the exposure duration of C1 in RSVP lists and found that the exposure duration of C1 did not affect the RB effect size. On the other hand, they showed that longer exposure duration of C2 decreased the effect size of RB. The reason(s) for the discrepant results between the two item and RSVP paradigm on the effect produced by the distinctiveness of C1 is not obvious. It may be due to the presence of distracters in RSVP paradigm, different memory demands, or different cognitive processes involved in these two paradigms. More systematic investigations are necessary to address these problems.

Researchers have also been interested in the effect of discriminability between C1 and C2 on RB. In the two-item paradigm, Humphreys et al. (1988) showed that RB changed to repetition priming when an intervening mask was added between prime and target. However, in order to keep the SOA between prime and target constant, the exposure duration of the prime was also shortened. Thus, the effect due to an intervening mask was confounded with the effect due to exposure duration of C1, as mentioned above.

Rather than adding a mask between C1 and C2 in the two-item paradigm to increase discriminability, Park and Kanwisher (1994a) manipulated the nature of intervening items between C1 and C2 in RSVP lists. In their experiment, C1 and C2 were separated by either a blank or a symbol with an equal interval. It is supposed that C1 and C2 were more discriminable in the blank condition. The results revealed that there was no interaction between the nature of intervening items and the repetition status. Park and Kanwisher (1994a) suggested that although the interaction did not reach significance statistically, the trend was in the direction that RB diminished in the blank condition and the effect would reach significance in more powerful experiments.

In sum, the issues involving encoding effectiveness of C1 are still controversial. Also, the effect of discriminability is not conclusive either. These are important issues that should be addressed because two of the most popular explanations of RB, the type-token binding failure hypothesis and the type refractoriness hypothesis, make different predictions of the effect due to the encoding effectiveness of C1 and the discriminability between C1 and C2 (e.g., Luo & Caramazza, 1995; see the section *Theoretical Accounts of RB*).

Selective Attention

Kanwisher (1991) asserted that one of the necessary conditions for the occurrence of RB is that C1 should be attended to and individuated. In one of her experiments (Experiment 6), some of the items in the RSVP lists were presented with color and participants were asked to report the colored items only. When C1s were white (i.e., no color) and C2s were colored, no RB was observed. RB was found only when both C1s and C2s were in color. In her previous work (Kanwisher, 1987, Experiment 3), RB changed to repetition priming when only the last word in a given RSVP list was required to be reported, indicating that RB occurs only when C1s have to be attended to individuate as an independent token.

Kanwisher et al. (1995) further showed that C1s should be attended to in the right dimension for the occurrence of RB. They presented two colored letters simultaneously. One group of the participants had to report the color of C1 and letter identity of C2, whereas another group did the opposite. In this case, both dimensions had to be attended to by participants and RB was found when both C1 and C2 were repeated in either dimension (i.e., letters, or colors). But when participants were required to report only one dimension (i.e., either to report the color of C1 and C2, or the identity of C1 and C2), no RB was observed for the ignored dimension and this is consistent with Kanwisher (1991). This implies that RB is sensitive to attentional demands.

Word frequency

Word frequency is one of the most popular variables usually included in the investigations of word recognition (Jared & Seidenberg, 1991; Seidenberg, 1985; Seidenberg et al., 1984) and repetition priming (Forster & Davis, 1984; Humphreys et al., 1988; Scarborough et al., 1977). On the contrary, RB research does not pay much attention to frequency effects on RB. To my knowledge, there are only two published studies on RB (Bavelier et al., 1994; Humphreys et al., 1988) manipulating word frequency as one of the independent variables. Humphreys et al. (1988), using an unmasked priming procedure, showed that the size of the repetition deficit was not affected by the word frequency of prime-target pairs. Similarly, Bavelier et al., (1994) also showed that when C1 and C2 were identical, the effect size of RB was not affected by frequency manipulations. However, Bavelier et al. (1994) cited a study conducted by Hochhaus & Mihura (1992) using a two-item paradigm, in which RB was only found in high frequency pairs but not in low frequency pairs. Bavelier et al. suggested that the discrepancy might be due to different experimental procedures adopted by these two studies. In summary, the word frequency effect on RB has not been systematically examined when C1 and C2 were identical[3].

Theoretical Accounts of RB

Since RB was originally demonstrated in RSVP recall tasks (Bavelier & Potter,

---

[3] Bavelier et al. (1994) has also investigated the frequency effect when C1 and C2 were orthographically similar. They showed that greater RB was found when C1 is a high orthographic neighbor of C2. Furthermore, only C1 frequency is critical to the effect size of RB such that high-frequency C1 induced greater RB. They claimed that such results are consistent with the priming studies in word recognition which demonstrated that high-frequency words inhibit their orthographic neighbors more rapidly (Segui & Grainger, 1990).

1992; Kanwisher, 1987), in which encoding, storage and retrieval operations are all required, different researchers have argued RB occurs at different stages and they proposed different theoretical accounts of RB.

Type refractory period hypothesis

The concept of a refractory period is common in the study of nervous system such that the a neuron has a refractory period after excitation. In the refractory period, re-excitation is impossible unless the refractory period is over, or more excitations are given. Similarly, the type refractory period hypothesis states that the occurrence of the first repeated item activates a corresponding mental representation (the type). After the activation, the type in turn suffers from a refractory period. Within that period, the type is inactive in that it either cannot be re-activated, or more excitations are required for re-activation. As a consequence, when two identical items are presented close in time, the second occurrence of the item may fall within the refractory period induced by the presence of the first presentation of the item, and hence is less likely to be perceived relative to unrepeated items. In short, RB is due to the inability to activate the same mental representation (the type) twice within a particular period of time.

Type-token binding failure hypothesis

According to the type-token binding failure hypothesis, there are two distinctive visual recognition processes, type recognition and token individuation. Type, as the same notion used in the type refractory period hypothesis, refers to the mental representation in long term memory. Token, on the other hand, refers to the episodic representation of an event or object. Kanwisher (1989) suggested that the nature and content of tokens is similar to object files, the episodic representations maintaining the identity and continuity of the perceived objects or events, as proposed by Kahneman & Treisman (1988; Kahneman, Treisman & Gibbs, 1992; see also Duncan, 1984; Gordon & Irwin, 1996 for the contents of object files). The distinction between type and token is similar to the distinction between semantic and episodic memory (Tulving, 1972). Thus, a token not only includes the identity (the type) of a perceived stimulus, but also its location, time, and other relevant information.

The complete process of visual recognition of a stimulus involves the activation of the correspondent type, the creation of a token, and the binding between the type and the token. The activation of the type enables people to recognize the corresponding identity. The creation of a token enables the collection of relevant information of that particular event such as "When" and "Where". The type-token binding, which is also called token-individuation (Kanwisher, 1987), enables the same identity to be assigned as two independent events.

The type-token binding failure hypothesis, also named as the token-individuation failure hypothesis, stated that when two identical items are presented close in time, there is a problem for the same type to bind with two tokens. Usually, the type can bind with the token corresponding to the first presentation of a stimulus but the binding between the type and the token corresponding to repeated stimulus fails. As a consequence, the repeated item cannot individuated as a token that contains the identity of the stimulus, and hence it is lost in sight[4].

---

[4] Bavelier (1994) demonstrated reverse RB in that when C2 is salient enough, C1 rather than C2 is lost.

Memory retrieval and output interference

Since RB was initially demonstrated in recall tasks (Bavelier & Potter, 1992; Kanwisher, 1987), some researchers (Armstrong & Mewhort, 1995; Fagot & Pashler, 1995; Whittlesea, Dorken & Podrouzek, 1995; Whittlesea & Podrouzek, 1995) raised the possibility that RB is not due to encoding failure as Kanwisher (1987) stated. Rather, it may occur at the storage, or retrieval stages of operation, or due to a response bias.

Whittlesea et al. (1995) showed that when sentences were presented in RSVP, C2 was often reported in the location of C1 but C1 was not reported in the location of C2, indicating that people has a general response bias to report C2 at location of C1, and hence C2 is usually reported as C1 (see Downing & Kanwisher, 1995 for criticism). They suggested that the processing of C1 is independent of the processing of C2 and claimed that evidence supporting the so called RB was actually due to a response bias of reporting C2 at location C1.

Fagot & Pashler (1995) regarded RB as a phenomenon that is similar to the Ranschburg Effect, a phenomenon whereby the reporting of the second occurrence of a repeated item is less accurate than that of an unrepeated item in full report of a series of items (Crowder & Melton, 1965; Jahnke, 1969). Although RB is found in the condition in which the presentation rate is relatively fast such as 150 ms/item or faster, and in contrast, Ranschburg effect is observed in much slower presentation rate such as 500 ms/item, Fagot and Pashler argued that RB and Ranschburg effect are not necessarily qualitatively different (see Fagot & Pashler, 1995, Appendix A).

The present study

Although RB has been widely investigated for ten years, some fundamental but critical issues are not clear. In particular, a number of alternative accounts proposed that RB occurs at different stages of information processing, as mentioned in previous sections. The reason different researchers attribute RB to different stages of processing seems to be related to the methodology initially used for the investigations of RB. Specifically, RB was generally measured in terms of the recall performance, which are off-line responses. Although Kanwisher (1987; Park & Kanwisher, 1994a) tried to rule out many possible off-line accounts of RB, the on-line encoding account she proposed was based on off-line performance. In order to provide more convincing evidence that RB involves an on-line encoding problem, one should demonstrate RB under a situation where storage and retrieval operations are at a minimum by collecting data reflecting more on-line performance.

The present study attempts to provide a more clear and direct examination of the encoding failure account of RB. The category monitoring task, in which both the reaction times and the error rates of the detection of the second target in an RSVP list, was adopted to provide a relatively more on-line measurement of RB in order to give more direct support that RB involves an encoding problem.

Another fundamental issue that is not clear is what happens to the repeated targets when they are successfully perceived/reported. Even if RB is a reasonably robust phenomenon, there is still a substantial number of trials in which the repeated items can be successfully perceived/reported. Past research measured RB exclusively in terms of error rate, and hence RB was seemed to be assumed as an all-or-none phenomenon such that the processing of repeated item was either as successful as the processing of the unrepeated items, or as unsuccessful in that it is completely lost from sight. It is doubtful whether such an assumption is true, especially since there is no (to my knowledge) study systematically investigating the successful processing of repeated items.

The experiments reported in the present study mainly examine the processing of the repeated item given that RB in terms of error rate occurs. In particular, it will focus on whether RB is an all-or-none phenomenon and the relationship between RB and repetition priming. Unlike the previous literature which used only error/correct rates to measure RB, I will collect both error rates and reaction times in order to provide a more direct reflection of what the processing of the repeated item involves. Also, some of the determinants of RB reported in previous studies are re-examined.

Experiment 1

The primary goal of Experiment 1 is to test whether RB can occur in a category counting task. In this task, participants have to report how many times a given category (i.e., animal) that they have seen in an RSVP list. Two presentation rates, 117 ms/item and 133 ms/item, were used because it has been shown that RB could be reliably demonstrated under these two presentation rates (Kanwisher, 1987; Kanwisher and Potter, 1989, 1990). If RB occurs, participants should be more likely to report "One" animal in a list containing repeated targets than in a list containing two unrepeated targets. It is also expected that RB will be diminished at the slower presentation rate (Kanwisher, 1987; Park & Kanwisher, 1994a).

The advantage of this task is the lower memory demand relative to conventional RSVP recall tasks, and hence, one can be more confident in interpreting that any RB observed does not reflect the retrieval stage of operations. Furthermore, a pilot study showed that the RSVP recall task with unrelated Chinese characters as stimuli is an extremely difficult task and that performance is at floor level. The category counting task, which are not so difficult, seems to be a more appropriate task for investigating RB in Chinese.

The second goal is to examine whether RB can be generalized to logographic Chinese (for reviews of language processing in Chinese, see, e.g., Chen, 1992, 1996; Hung & Tzeng, 1981). Since previous research on RB had used English or other alphabetic languages such as Spanish letters or words as stimuli, and it has been shown that lexical processing and memory can vary across different writing systems (Chen & Juola, 1982; Frost, Katz, & Bentin, 1987; Simpson & Kang, 1994), it is necessary to show that RB can be found in Chinese before conducting other investigations of RB using Chinese as stimuli.

A similar procedure was used with English in a study by Park and Kanwisher (1994, Experiment 7). They asked participants to indicate how many vowel letters they had seen in an RSVP list. By using signal detection analysis, they found that it was less sensitive to detect two vowels which were identical than those which were different when the lag between the two critical vowels was small. However, the task used in Experiment 1 was different from that of Park and Kanwisher's in two ways. First, English letters were used in their study while structurally more complex Chinese characters were used in Experiment 1. Second, participants were asked to do a phonological categorization task (vowel detection) in Park and Kanwisher's study, whereas participants were asked to do a semantic categorization task (animals detection) in Experiment 1.

Method

Participants. Fourteen undergraduate and graduate students from the Chinese University of Hong Kong were recruited as volunteers in this experiment. All of them were native Cantonese speakers with normal or corrected to normal vision.

Materials and Design. Each stimulus consisted of an RSVP sequence of six Chinese characters. A total of 240 experimental trials were constructed in which 80 contained non-target characters only, 80 contained one target character (i.e., a character representing animal in meaning) and 80 contained two target characters. Half of the trails (i.e., 40 trails) with two target characters contained repeated target characters (i.e., repeated condition), whereas the other half contained unrepeated target characters (i.e., unrepeated condition). The target characters (C1 and C2) appeared either at the 2nd and 4th or 3rd and 5th serial positions, respectively. Five Chinese animal characters (Dog, Chicken, Fish, Horse and Mouse) were selected as targets and non-animal characters were selected randomly without repetition from a Chinese corpus consisting of 1080 Chinese characters with frequency ranging from 100-400 per million (Hong Kong Education Department, 1986). Each of the five animal characters would appear at the C2 position 24 times, eight times with the identical target at C1, eight times with the four other targets appearing at C1 evenly and eight times with a non-target at C1. Each type of target would also appear at C1 eight times while non targets were at C2.

There were two independent variables in this experiment. The repetition status (repeat vs. unrepeated) was the within-subjects variable and the presentation rate (117 ms/item vs. 133 ms/item) was the between-subjects variable.

Apparatus. The experiment was controlled by an IBM 80486 compatible computer with a Super VGA monitor. The experiment was conducted in a computer laboratory with slightly dim illumination.

Procedure. At the beginning of the experiment, participants were instructed that there would be up to two animal characters in each RSVP list and they have to type into the computer keyboard the number of animal characters they saw in a given RSVP list regardless of whether the animal characters were repeated or not. For each trail, six successive Chinese characters, which were preceded and followed by an asterisk for 1500 ms and 500 ms respectively, were presented at the center of the computer screen. A prompt then appeared on the screen and asked participants to type the number of animal characters they saw. After inputting the number, another trail was began by pressing the space bar. All characters were displayed for 117 ms for half of the participants and 133 ms for the other half. There were 30 practice trails in which all characters were displayed for 300 ms to familiarize the participants with the experiment procedures. The whole experiment lasted for about 45 minutes.

Results and Discussion

Only the data from the two target lists were relevant for analyses (The mean error rates for lists with one target character and without target character were 1.7% and 1.8%, respectively). Since only five animal characters were selected as targets, item-based analysis was not so meaningful with such a small number of items, and hence item-based analysis was not carried out in Experiment 1. The results showed that there was a significant main effect for repetition status, $F(1, 12) = 4.85$, $MSE = 7.76$, $p < 0.05$. As shown in Table 2, lists containing two repeated targets were more likely to be judged as containing only one animal character than those containing two unrepeated targets. Although there was a trend showing that more judgment errors were found in the faster presentation rate, the main effect of presentation rate failed to reach significance, $F(1, 12) = 3.09$, $p > 0.1$. The repetition status × presentation rate interaction was not significant either, $F < 1$.

Table 2.

Percentage of trials in which subjects detected one target in the two-target lists as a function of repetition status and character display duration in Experiment 1.

	Condition	
Presentation rate	Repeated (%)	Unrepeated (%)
117 ms/item	7.1	4.4
133 ms/item	2.6	0.7

The results of Experiment 1 clearly indicate that the RSVP category counting task is sensitive enough to generate RB. Also, RB can be generalized to logographic Chinese characters. The results are also consistent with other studies which observed RB in RSVP recall tasks by using English words as stimuli (Kanwisher, 1987; Kanwisher & Potter, 1989, 1990), except that no repetition status × presentation rate interaction was found in Experiment 1. It is probably because the presentation rates were too closely spaced from a large contrast, as indicated by the fact that no main effect of presentation rate alone was found. Thus, Experiment 1 has established the ground for using the category counting task for RB research and Chinese characters as stimuli in the following experiments.

Experiment 2

Although a significant RB effect was observed in Experiment 1, over 90% of the repeated targets could be successfully reported. What happens to those repeated targets which could successfully be reported? Is RB an all-or-none phenomenon such that the processing of the repeated targets the same as that of the unrepeated targets in RSVP lists? The reaction time data to the second targets which can be successfully responded are the critical information to answer the above questions. RB research, however, has exclusively used error rates as the dependent variable, whereas what happens to the correct responses of the repeated targets is generally ignored. To my knowledge, only one published RB study conducted by Whittlesea et al. (1995, Experiment 3a-3d), in which participants were asked to name the final word in an RSVP list and to indicate whether or not it was repeated in the list, collected reaction time as one of the dependent variables.

However, their results cannot clearly show whether RB can be generalized to reaction time data for several reasons. First, the last word naming task they adopted does not provide a consistent RB effect. As mentioned above, Kanwisher (1987, Experiment 3) found repetition priming while Kanwisher and Potter (1990, Experiment 6) observed repetition blindness in the last word naming task. It is not clear whether this task is a reliable task for the occurrence of RB. Second, their error rates did not show RB either. It is questionable whether there was an RB effect in their experiments and hence interpreting the reaction time data becomes uncertain. Third, their experiments did not give consistent results such that null effect, repetition priming and RB were all observed in reaction time. Finally, their primary purpose for using the last word naming task was to test whether repetition priming, not RB, can be observed.

Due to such limitations, a more systematic investigation of RB in reaction times is necessary.

The category counting task in Experiment 1 was modified in order to collect reaction time data on the second target in this experiment. Participants were asked to make responses to the second occurrence of an animal character in RSVP lists. It is worthwhile to note that, in this category monitoring task, both the reaction time and the rates of misses on the second occurrence of the targets can be collected. The immediate responses can reflect the on-line processing of the repeated targets as well as enable direct comparison between the processing of the repeated and unrepeated targets. If RB is due to the processing difficulty induced by the repeated item, successful responses to the repeated targets should be longer than those of unrepeated ones. On the other hand, if RB is an all-or-none phenomenon, the processing of the successfully perceived items in the repeated condition should not be different from that of the unrepeated repeated condition, and hence response times to the repeated item should not be different from those to the unrepeated one.

As in Experiment 1, two presentation rates were used. The first presentation rate adopted was 117 ms/item because it was found sensitive enough to generate the RB effect in Experiment 1. Since the effect of presentation rate in Experiment 1 was not significant, a much slower presentation rate, 200 ms/item, was also adopted to amplify its effect. Furthermore, it has been shown that the fixation duration in normal reading is about 250 ms in English (Rayner & Pollatsek, 1989) and 190 ms in Chinese (Inhoff & Liu, 1997), thus a presentation rate of 200 ms/item is reasonable for the investigation of how the repeated items are processed in a situation that closely resembles normal reading.

Method

Participants. Twenty undergraduate or graduate students from the Chinese University of Hong Kong were recruited as volunteers in this experiment. All of them were native Cantonese speakers with normal or corrected to normal vision. None of them had participated in Experiment 1.

Materials and Design. Materials and design in the present experiment were basically the same as those used in Experiment 1, except that only lists containing one target and lists containing two targets were included, and the 133 ms/item presentation rate was changed to 200 ms/item. Therefore, there were total 160 experimental trials.

Apparatus. The experiment was controlled by an IBM 80486 compatible computer with a Super VGA monitor. The experiment was conducted in a computer laboratory with slightly dim illumination.

Procedure. Most aspects of the procedure were the same as those of Experiment 1, expect that participants were instructed to press the space bar on the keyboard as quickly and as accurately as possible whenever they saw the second occurrence of an animal character in a given RSVP list regardless of whether the animal character was repeated or not. All characters were displayed for 117 ms for half of the participants and 200 ms for the other half. There were 30 practice trails in which all characters were displayed for 300 ms for participants to be familiarized with the experiment procedures. The whole experiment lasted for about 30 minutes.

Results and Discussion.

Only the data from the two target lists were used for analyses. Trials with responses made before the appearance of the second animal character (1%), or with reaction times longer than 1000ms or shorter than 100 ms (2%) were discarded from analyses[5]. The false alarm rate, i.e., hitting when only one animal occurred, was 15%. Figure 1 shows the mean reaction times and mean error rates for the two target lists. Since only five animal characters were selected as targets, item-based analysis was not so meaningful with such a small number of items, and hence item-based analysis was not carried out in Experiment 2.

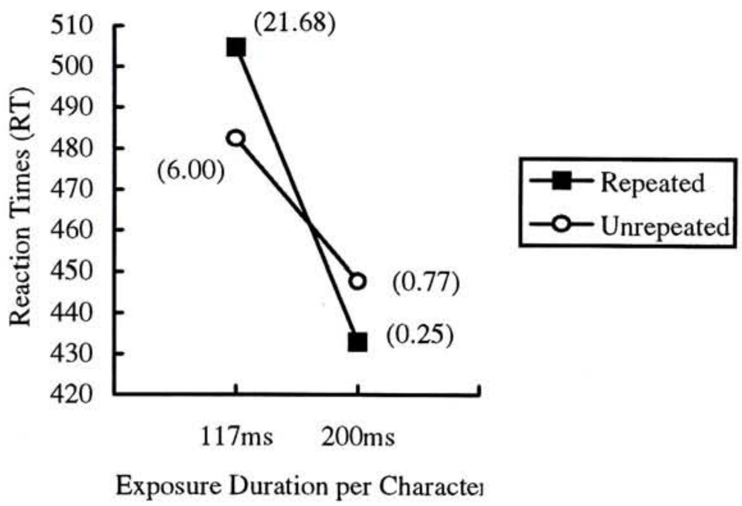

Figure 1: *Mean reaction times and percentages of error (in parentheses) as a function of repetition status and character display duration in Experiment 2*

For error rates, all main effects and the interaction were significant: Repetition status, $F(1, 18) = 24.67$, $MSE = 24.91$, $p < 0.001$; presentation rate, $F(1, 18) = 15.62$, $MSE = 122.50$, $p < 0.05$; and repetition status × presentation rate, $F(1, 18) = 24.70$,

---

[5] The 1000 ms cutoff criterion is one of the commonly adopted trimming methods for mean reaction times ranged 400-700 ms (e.g., Fleming, 1993; Grainger & Ferrand, 1996; Jared, 1997)

$MSE = 24.91$, $p < 0.001$. More errors were found in the repeated condition relative to unrepeated condition when the presentation rate was 117 ms/item, $t(9) = 4.97$ $p < 0.05$, replicating Experiment 1 that RB occurred when presentation rate was 117 ms/item. There was no significant difference between repeated and unrepeated condition when presentation rate is 200 ms/item.

For the analyses of reaction time, the general pattern was similar to that of error rates. The main effect of repetition status was only marginally significant, $F(1, 18) = 4.26$, $MSE = 7262.29$, $p = 0.054$. However, the repetition $\times$ presentation rate interaction reached significance, $F(1, 18) = 17.12$, $MSE = 242.65$, $p < 0.05$. The main effect of presentation rate was insignificant. Specifically, the reaction time in repeated condition was longer than that in unrepeated condition when the presentation rate was 117 ms/item, $t(9) = 2.69$, $p < 0.05$. When the presentation rate was 200 ms/item, responses in unrepeated condition were longer than those in repeated condition, $t(9) = -2.93$, $p < 0.05$. Thus, RB changed to repetition priming by decreasing the presentation rate.

The most important finding in Experiment 2 is that when RB occurs, as indicated by the higher error rates in the repeated condition as compared to the unrepeated condition and when presentation rate was fast (i.e., 117 ms/item), the processing times of successfully responded repeated stimuli are longer than those of unrepeated stimuli. This suggests that RB is not just an all-or-none dichotomy but it is due to processing difficulty in the repeated condition. It also suggests that the reaction time data of the second target provides meaningful information about the on-line processing of the second target which is important for us to understand more about RB.

Experiment 2 not only replicated that RB diminished in slow presentation rate

(Kanwisher, 1987; Park & Kanwisher, 1994a), it is also extended to reaction times in that repetition facilitation was observed in the slow presentation rate. The repetition priming observed in the slow condition is consistent with the claim that the algorithmic process of a repeated target is replaced by a more rapid memory-based repetition-detection process (Arbuthnott, 1996; Bentin & McCarthy, 1994; Logan, 1990). That is, the still active algorithmic product from C1 is available in working memory such that no more computational operations are necessary for C2 identification when C2 is identical to C1.

The storage or retrieval accounts of RB seems to be inconsistent with the results of Experiment 2 in which storage and retreival operations were minimal (relative to the conventional RSVP recall tasks). Fagot & Pashler (1995) argued that although RB and Ranschburg effect are observed in different presentation rates, these effects are not necessarily qualitatively different. However, the changing of RB to repetition priming in reaction times of the on-line detection of the second repeated targets in the present study further challenges any account regarding RB as a phenomenon that does not involve encoding failure.

Experiment 3

Experiment 3 examines whether the RB and repetition priming found in reaction time data from Experiment 2 can also be observed in the two-item paradigm. This was done by presenting only the two target characters separated temporally by a mask and asking participants to indicate whether there were one or two animal characters. Moreover, since only five animal characters were used repeatedly throughout Experiments 1 and 2, the present experiment used 14 animal characters presented without repetition in order to generalize RB to a wider range of stimuli.

The exposure duration of the critical items was shortened to be 70 ms and 100 ms in the fast condition and remained at 200 ms in the slow condition. The reason a shorter exposure duration was used is because relatively shorter exposure durations of C2 are necessary for the occurrence of RB in two-item paradigm (Hochhaus & Marohn, 1991; Humphreys et al., 1988; Luo and Caramazza, 1995), probably due to the fact that the effect of RB diminished when C1 or C2 was the first or the last item in an RSVP list (Kanwisher, 1991).

Method

Participants. Sixty undergraduate students from an introductory psychology course at the Chinese University of Hong Kong participated in this experiment. All of them were native Cantonese speakers with normal or corrected to normal vision. None of them had participated in the previous experiments.

Materials and Design. Each trial consisted of two Chinese characters. There was a total of 42 trials in the experiment, 14 containing two targets and 28 containing one target. Trails containing two targets were subdivided into two conditions: repeated and unrepeated with 7 trials for each condition, with 14 Chinese animal characters were selected to act as C2. In the repeated condition, C1s were identical to C2s, while in the unrepeated condition, C1s were animal character controls that were matched in number of strokes and word frequency to the C2s. Two versions of the experiment were constructed such that if C1 was identical to C2 in one version, it would be the matched control in the other. Half of the participants received one version and half the other. Another 28 animal characters, half of them acting as C1 while the other half acting as

C2, were selected and used only in trails containing one target. The list of the 14 pairs experimental and 28 fillers materials used is given in Appendix A.

There were two independent variables. The within-subjects variable repetition status (repeated vs. unrepeated) was counterbalanced across two lists so that each item appeared only once in the experiment. Another independent variable presentation duration (70 ms, 100 ms and 200 ms) was manipulated between-subjects.

Apparatus. The experiment was controlled by an IBM 80486 compatible computer with a Super VGA monitor. The experiment was conducted in a computer laboratory with slightly dim illumination.

Procedure. At the beginning of the experiment, participants were instructed that each trial would contain two characters separated by a mask. Either one or two animal characters were included in each trail and they should press the key corresponding to two animals as quickly and as accurately as possible when they saw two animal characters regardless of whether they were repeated or not, whereas they should press the key corresponding to one animal as quickly and as accurately as possible when they saw one animal character. For each trial, a asterisk would appeared on the screen for 1500 ms, then C1, an asterisk, C2, and another asterisk appeared at the same location on the screen successively. The final asterisk remained on the screen until a response was made. The presentation duration of the C1, C2 and the asterisk masked between C1 and C2 was either 70 ms, 100 ms or 200 ms accordingly. The presentation order was randomized for each participants. There were 15 practice trails in which all characters were presented for 300 ms. The whole experiment lasted for about 15 minutes.

Results and Discussion

Only the responses for the trails containing two targets were relevant to the analyses (the error rates for trails containing one target were 7.8%). Responses longer than 1500 ms or shorter than 100 ms (3.6%) were discarded from analyses[6]. The mean reaction times for correct responses and error rates were calculated across subjects and items separately and was subjected to a separate 2 (Repetition status: repeated vs. unrepeated) $\times$ 3 (Presentation duration: 70 ms, 100 ms or 200 ms) analysis of variance (ANOVA) in that *F1* and *t1* refers to the subject-based analysis and *F2* and *t2* refers to the item-based analysis. Table 3 summarizes the mean reaction times for correct responses and error rates across subjects as a function of presentation duration.

Table 3 .

Mean reaction times for correct responses and percentages of error (in parentheses) as a function of repetition status and presentation duration in Experiment 3.

	Presentation Duration (ms)		
	70	100	200
Repeated	804 (3.6)	780 (5.0)	626 (5.0)
Unrepeated	745 (4.3)	754 (4.3)	672 (2.1)

For reaction times analyses, the main effect of presentation duration was significant, *F1* (2, 57) = 6.15, $p < 0.01$; *F2* (2, 26) = 27.51, $p < 0.001$; but the main

[6] The 1500 ms cutoff criterion is one of the commonly adopted trimming methods for mean reaction times ranged 600-900 ms (e.g., Altarriba & Mathis, 1997; Jared & Seidenberg, 1991)

effect of repetition status did not reach significance, *Fs* < 1. However, there was a significant repetition status × presentation duration interaction, $F1$ (2, 57) = 4.62, $p <$ 0.05; $F2$ (2, 26) = 22.15, $p < 0.001$. No significant effects were observed in the error rates data, probably due to the high accuracy across all conditions. Thus, it indicates sometimes error rates alone may not be sensitive enough to differentiate repeated and unrepeated responses, illustrating that reaction times data is the important information that should not be ignored.

The general pattern in Experiment 3 was very similar to that in Experiment 2. Repetition deficit was observed in reaction times data when the presentation duration was short, as indicated by responses times in repeated conditions were longer than those in unrepeated condition when presentation duration was 70 ms, $t1$ (19) = 2.27, $p < 0.05$; $t2$ (13) = 3.40, $p < 0.01$; whereas the effect reversed to repetition priming as the presentation duration became longer as indicated by responses times in repeated condition was faster than those in unrepeated condition when presentation rate was 200 ms, $t1$ (19) = 2.19, $p < 0.05$; $t2$ (13) = 2.36, $p < 0.05$. There was no significant difference between repeated and unrepeated condition when presentation rate was 100 ms. Therefore, RB and repetition priming found in the reaction times are extended to two-item paradigm. Furthermore, RB and repetition priming effects were generalized across both subjects and items in a larger stimulus set. Experiment 3 also replicated the repetition priming observed in Experiment 2 when the presentation duration was 200 ms. The relationship between RB and repetition priming will be discussed later in General Discussion.

Hochhaus & Johnston (1996) suggested that one should observe the same pattern of results both in RSVP and two-item paradigm across different manipulations if RB observed in their single-frame paradigm and other two-item paradigm is the same as RB observed in RSVP paradigm. The overall pattern observed in Experiment 3 is very similar to that in Experiment 2, especially the changing of RB to repetition priming when the presentation duration was lengthened. The results of Experiments 2 and 3 were only diverge in that no reliable RB in error rates was observed in Experiment 3, probably due to the ceiling level performance masking out the repetition effect. The similarity between Experiments 2 and 3 suggests that RB observed in RSVP and two-item paradigm may be the same.

It should be noted that the procedures adopted in the present experiment are very similar to those in masked priming studies. The significant RB effect observed in this experiment, however, seems to be contradictory to Humphreys et al.'s (1988) study in which repetition priming was observed when the prime was masked or prime and target were intervened by a mask. One of the possible explanations of such discrepancy is that the priming words in Humphreys et al.'s were not required to be reported, whereas C1s in the present study should be recognized as an independent event in order to give correct responses. Since it has been shown that whether the results show RB or repetition priming is dependent on the nature of task about whether C1 should be reported/attended or not (Kanwisher, 1987), this issue was further examined in Experiment 4.

Experiment 4

There was no converging result about the effect of whether C1 is necessary to be reported for the occurrence of RB. Sometimes RB changed to repetition priming (Humphreys et al., 1988; Kanwisher, 1987) while sometimes RB remained (Kanwisher and Potter, 1990; Luo and Caramazza, 1995) when C1 was not necessary to be reported. The different materials and experimental procedures used among these studies make the direct comparison to be impossible.

In order to solve such problem and directly compare the effect due to the nature of task, most of the aspects in Experiment 4 were the same as those in Experiment 3, except that participants were required to judge whether C2s, rather than both C1s and C2s, were animal character or not only. Stimuli were only presented for 70 ms because it was the only presentation duration generated reliable RB in Experiment 3.

Method

Participants. Twenty undergraduate students from an introductory psychology course at the Chinese University of Hong Kong participated in this experiment. All of them were native Cantonese speakers with normal or corrected to normal vision. None of them had participated in the previous experiments.

Materials and Design. Materials and design were the same as those in Experiment 3, except that (a) 14 filler trials that containing no target were added in order to increase the proportion of trails that C2s were not animal characters, and (b) only the presentation duration 70 ms was used.

Procedure. Procedure was the same as that in Experiment 3, except that participants were instructed that in each trial they should ignore C1 and press "Yes" button when C2 was an animal character or press "No" button when C2 was not an animal character.

Results and Discussion

Only the responses for the trails containing both C1 and C2 were relevant to the analyses (the error rates for other trails were 8.1%). Response latencies longer than 1500 ms or shorter than 100 ms (9.3%) were discarded from analyses. The mean reaction times for correct responses and error rates were calculated across subjects and items separately. The mean reaction times and error rates across subjects were shown in Table 4. Response times in unrepeated condition tended to be slower than those in the repeated condition, but the difference was only significant in item analysis, $t1 < 1$; $t2$ $(13) = 2.55$, $p < 0.05$. No significant difference was found in error rates.

Table 4.

Mean reaction times of correct responses and error rates in repeated and unrepeated conditions in Experiment 4.

	Conditions	
	Repeated	Unrepeated
Reaction Times (ms)	790.39	819.13
Error Rates (%)	7.1	6.4

In order to compare the effect of nature of task, data from Experiment 3 at presentation rate 70 ms were combined with data from Experiment 4. A 2 (Repetition status: repeated vs. unrepeated) × 2 (Nature of task: Experiment 3 vs. Experiment 4) ANOVA showed that there was a significant repetition status × nature of task interaction, $F1$ $(1, 38) = 4.51$, $p < 0.05$; $F2$ $(1, 13) = 16.48$, $p < 0.01$, indicating that RB was changed to repetition priming when the task was changed to that C1s are not necessary to be responded to (Fig. 2). The main effect of repetition status and nature of task were not significant, as well as no any significant effect was found in error rates.

When the within-subject patterns were considered, since the experimental materials, presentation conditions and number of subjects were the same across these two experiments, whether C1s should be responded is the most likely factor accounting for the repetition status × nature of task interaction[7]. With a closer inspection of Experiment 3 and Experiment 4, it was observed that longer reaction times in unrepeated conditions and more error rates were found in Experiment 4. Since it was a between-subject comparison, such differences might be due to different task difficulties, individual variations, or other factors, which make the interpretation of the interaction involves between-subject factors become somewhat difficult. Nevertheless, since the conventional RSVP recall tasks, in which much more error rates were observed, were believed to be more difficult than Experiment 4, it is unlikely that RB in Experiment 3 changed to repetition priming in Experiment 4 was due to that Experiment 4 was a more difficult task. Nevertheless, further investigation is needed to confirm such speculation.

---

[7] It should be noted that Experiment 3 and 4 are also different in the number of trials and the proportion of responses. However, there is no evidence indicating that the pattern of RB changed as the number of trials increased (Kanwisher, Kim & Wickens, 1996), and only 14 trials was added. The proportion of responses (i.e., the Yes to No ratio) was also not changed much, from 1:2 to 1:1, and past research observed reliable RB generally maintained the repeated to unrepeated trials ratio at 1:1, and hence the ratio change is unlikely to contribute the pattern changes in Experiment 3 and 4.

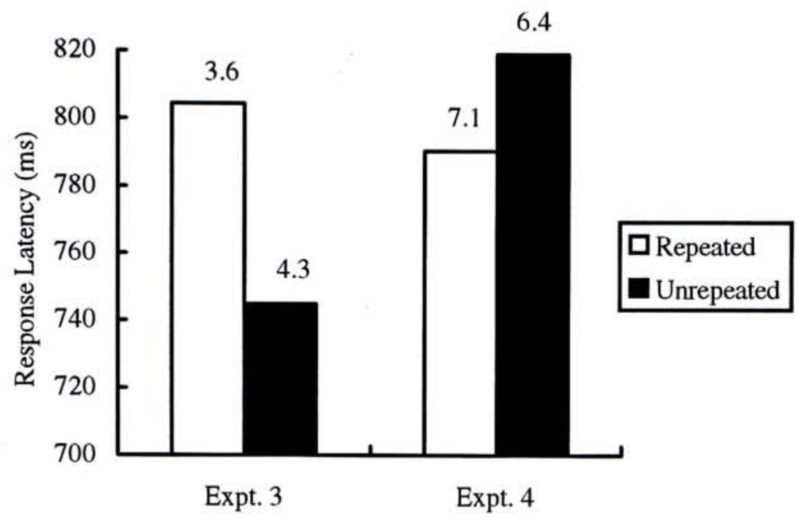

Figure 2: *Mean reaction times and percentages of error (values above the bar) as a function of repetition status and natural of task.*

Luo and Caramazza (1995) argued that type refractoriness hypothesis and type-token binding failure hypothesis make different predictions on whether C1 is necessary to be attended/reported or not. That is, if RB is the result of type-token binding failure as proposed by Kanwisher (1987; Park & Kanwisher, 1994a), token individuation of C1 is a necessary condition for the occurrence of RB. If RB is the result of type-refractoriness, effective encoding of C1 above threshold is a necessary condition for the occurrence of RB (Luo and Caramazza, 1995, 1996). Therefore, they reasoned that "type refractoriness hypothesis ... predicts RB to occur independently of whether C1 was to be reported or not (provided it was processed)" (Luo & Caramazza, 1995, p.1063). They found RB even when C1 was not necessary to be reported and the effect size of RB increased as the exposure duration of C1 increased, and they regarded this as the evidence against type-token binding failure.

Thus, once the C1 is encoded above threshold, type refractoriness hypothesis predicts that RB should occur regardless of whether C1 is necessary to be reported or not. The significant repetition status × nature of task interaction indicating that RB changed to repetition priming when C1 was not necessary to be responded to, suggests that the necessary condition of RB is C1 should be responded to. This is contradictory to the prediction of type refractoriness hypothesis according to the reasoning of Luo and Caramazza (1995).

However, it should be clarified whether there is any difference between the notions "type-token binding" and "supraliminal perception". Since tokens refer to the representation in episodic memory, if a type does not bind with a token, it cannot be recognized at the level of consciousness (Kanwisher, 1991). Similarly, effective encoding of C1 supraliminally also refers to the recognition that is at the level of consciousness. It seems that type-token binding is the final step for a supraliminal perception. Only subliminal perception was found if there is no type-token binding, and supraliminal perception is the result of type-token binding. Therefore, the necessary conditions for RB according to type-token binding failure hypothesis (i.e., token individuation of C1) and type refractoriness hypothesis (i.e., effective encoding of C1 above threshold) are functionally the same in the sense that C1 should be processed up to conscious level. Therefore, manipulating whether C1 should be responded to or not cannot differentiate type-token binding failure hypothesis and type refractory period hypothesis. I will return to this issue in General Discussion.

Then, why significant RB was observed by Luo and Caramazza (1995, Experiment 2) when C1 was not necessary to be reported but it changed to repetition priming in the present experiment. This discrepancy seems to due to the fact that the presentation location of C1 and C2 were not fixed in their experiment. As suggested by Luo and Caramazza (1995), the uncertain presentation location of C1 and the abrupt onset of

C1 in their experimental procedure would capture the attention of participants, and hence actually C1 was attended (and individuated) by participants in their study which in turn may lower the recognition threshold to induce RB. Thus, based on these results, RB is not likely to be determined by the absolute exposure duration of C1 but it is sensitive to the attention allocation.

Experiment 5

As mentioned above, type-token binding failure hypothesis and type refractory period hypothesis cannot be differentiated by manipulating whether C1 should be attended. In Experiment 5, the discrminablility between C1 and C2 was manipulated to examine this two hypotheses. This was done by manipulating the nature of the mask between C1 and C2. Park and Kanwisher (1994a) manipulated the nature of intervening item between C1 and C2 in a string of RSVP list. They found that although statistically failed to reach significance, the effect size of RB tended to be smaller when C1 and C2 were intervened by blanks than when intervened by symbols. It seems to suggest that the more discriminable between C1 and C2 are, the lesser the RB was found. In Experiment 5, two types of mask were used, symbols and Chinese non-characters. Since C1 and C2 were Chinese characters, it is assumed that it is less discriminable when C1 and C2 are intervened by a Chinese non-character than when they are intervened by a symbol.

The demonstration of the dependency of RB on the discriminability between C1 and C2 is important to the underlying mechanism of RB. According to Luo and Caramazza (1995), RB is the result of a refractory period induced by effective supraliminal encoding of C1. Since the masks between C1 and C2 are presented after the encoding of C1, it is unlikely that the presence of less discriminable masks would lengthen the refractoriness period in the sense that all processing of C1 should be inactivated in this period. Thus, according to the type-refractoriness hypothesis proposed by Luo and Caramazza (1995, 1996), repetition status should not interact with the nature of mask separating C1 and C2.

According to Kanwisher (1987), RB is the due to that the failure of a repeatedly activated type binds with a new token. If so, RB should be independent of the discriminability between C1 and C2. However, it is still possible that the repeatedly activated type incorrectly binds with the token created before as if the case of apparent motion. If so, the effect of RB should be greater when C1 and C2 are more indiscriminable. In sum, if nature of mask interacts with repetition status, it will create a problem to type refractory period hypothesis and type-token binding failure hypothesis which asserts that RB is due to the failure of the binding between the type to a new token, rather than due to the incorrect binding of the type to the token created before.

Another variable of interest is the effect of the characters frequency. Bavelier et al. (1994) showed that RB was not affected by the absolute frequency of the critical words in RSVP recall task, whereas another study (e.g., Hochhaus & Mihura, 1992, cited in Bavelier et al., 1994) showed that repetition blindness was only restricted to high frequency words in two-item paradigm. Bavelier et al. (1994) suggested that such discrepancy might be due to the different paradigms adopted by these two studies. However, both studies only collected error rates as dependent variable. As shown in Experiment 3, RB was observed in reaction times but not in error rates, it is possible that sometimes error rates alone may not be sensitive enough to capture the week frequency effect. In Experiment 5, a similar procedure to that of Experiment 3 was used to collect both reaction times and error rates and the target characters were divided into high or low frequency group to examine the frequency effect on RB.

Another purpose of Experiment 5 is to generalize the RB obtained in Experiment 3 to other categories. Specifically, whereas only one category, animal, was used in all trials of Experiment 3, the category was changed every trial in Experiment 5. That is, participants had to decide whether two sequentially presented Chinese characters are *both* the exemplars of the previous category which is presented at the beginning of each trial. This procedure is similar to the semantic categorization tasks which as been widely adopted to study word recognition (Chen et al., 1995; Jared & Seidenberg, 1991; Van Orden, 1987; Van Orden et al, 1988), except that in the present experiment (a) participants have to make decision for two sequentially presented items rather than one, and (b) the stimuli were presented more brief (i.e., 70 ms).

Method

Participants. Thirty-two undergraduate students from an introductory psychology course at the Chinese University of Hong Kong participated in this experiment. All of them were native Cantonese speakers with normal or corrected to normal vision. None of them had participated in the previous experiments.

Materials and Design. Each participant saw 192 experimental trials, in which 64 contained two exemplars of a given category, 64 contained one exemplar at C1, and 64 contained one exemplar at C2. Five symbols (i.e., @, #, $, %, &) and five Chinese non-characters which were composed by re-arranging character components in illegal positions were selected to act as the masks between C1 and C2. 32 high frequency Chinese characters and 32 low frequency Chinese characters were used in the trials containing two exemplars. Mean frequency were 321 per million for high frequency characters and were lower than 30 per million for low frequency characters[8]. For half of the trails of either frequency group, C1 was identical to C2 (i.e., repeated condition), whereas in the other half C1 was character control (i.e., unrepeated condition) with the same category of C2, and C1 was matched with C2 in character frequency and number of strokes. The mean frequency were 359 per million for the high frequency control and were lower than 30 per million for low frequency control. All materials are given in Appendix B. Each of the composition of the frequency × repetition status was further divided into two groups, where symbols acted as the masks between C1s and C2s in one group and Chinese non-characters were used in the other. Repetition status (repeated vs. unrepeated) and natural of mask (symbols vs. non-characters) were counterbalanced across items and subjects. Character frequency was a between-item variable. There were 4 versions of experiment for each frequency group formed by crossing repetition status and nature of mask. Therefore, each pair of exemplars would appear once for each participant.

Apparatus. The experiment was controlled by an IBM Pentium compatible computer with a Super VGA monition. The experiment was conducted in a computer laboratory with slightly dim illumination. The software used for creating and running the experiments was DMASTR system developed at Monash University and at the University of Arizona.

Procedure. For each trial, a category name appeared at the center of the computer

---

[8] The frequency count I used does not show characters with frequency lower than 30 occurrences per million. All of the characters in low frequency condition are not included in the frequency count and hence it should be lower than 30 occurrences per million.

screen for 1680 ms. It was then replaced by a pattern mask as fixation point for 1470 ms. C1, a mask (either symbols or non-characters) and C2 were then presented sequentially at the fixation location for 70 ms each and followed by another pattern mask which remained on the screen until a response was made or after 8000 ms if there was no response. At the beginning of the experiment, participants were instructed that each trial would contain two characters that either only one or both were the exemplars of the given category. They should press the key corresponding to "TWO" as quickly and as accurately as possible when they saw two exemplars regardless whether they were repeated or not, whereas they should press the key corresponding to "ONE" as quickly and as accurately as possible when they saw one exemplar only. There were 9 practice trails in which all characters were presented for 210 ms to familiarize participants with the procedure. The whole experiment lasted for about 30 minutes.

Results

Only responses for the trails containing two targets were relevant to the analyses (the error rates for trails containing one target were 24.8%). Responses longer than 1500 ms or shorter than 100 ms (3.2%) were discarded from analyses. An item was discarded from reaction times analyses because all of its responses were either incorrect or longer than 1500 ms in one of the conditions. The mean reaction times for correct responses and error rates were calculated across subjects and items separately and was subjected to a separate 2 (Frequency: high frequency pairs vs. low frequency pairs) × 2 (Repetition status: repeated vs. unrepeated) × 2 (Nature of mask: non-characters vs. symbols) ANOVA in that *F1* refers to the subject-based analysis and *F2* refers to the item-based analysis. Table 5 summarizes the mean reaction times for correct responses and error rates.

Table 5

Mean reaction times (ms) for correct responses and percentages of errors (in parentheses) in trails containing two targets of Experiment 5

	High frequency pairs		Low frequency pairs	
Conditions	non-characters	symbols	non-characters	symbols
Repeated	873 (30)	777 (13)	875 (23)	810 (13)
Unrepeated	831 (24)	745 (9)	826 (18)	836 (12)

Response latencies. The main effect of nature of mask was significant, $F1$ $(1, 31) = 14.79$, $MSE = 15136$, $p < 0.005$; $F2$ $(1, 61) = 17.28$, $MSE = 11210$, $p < 0.0001$, indicating targets separated by non-character (851 ms) were needed to take longer time to respond than targets separated by symbols (792 ms). The main effect of frequency was marginally significant in subject-based analysis, $F1$ $(1, 31) = 3.56$, $MSE = 17024$, $p = 0.069$, but not significant in item-based analysis. Response latencies for low frequency pairs (837 ms) tended to be longer than those for high frequency pairs (807 ms). Although the main effect of repetition status did not reach significance, there was a marginal significant repetition status × nature of mask interaction in subject-based analysis, $F1$ $(1, 31) = 3.58$, $MSE = 7924$, $p = 0.068$; but not significant in item-based analysis. RB was tended to be greater when C1 and C2 were separated by non-characters (46 ms) than by symbols (3 ms). Finally, there was a significant frequency × nature of mask interaction, $F1$ $(1, 31) = 6.85$, $MSE = 9580$, $p < 0.05$; $F2$ $(1, 61) = 6.41$, $MSE = 11210$, $p < 0.05$, indicating that the effect of nature of mask was stronger in high frequency pairs (91 ms) than in low frequency pairs (28 ms). No other effect approached significance (all *ps* > 0.05).

Percentage of errors. The main effect of repetition status was significant, $F1$ (1, 31) = 4.31, $MSE = 227$, $p < 0.05$; $F2$ (1, 62) = 8.26, $MSE = 163$, $p < 0.005$, indicating that more errors were made in repeated condition (20 %) than in unrepeated condition (16 %). The main effect of mask was also significant, $F1$ (1, 31) = 24.32, $MSE = 374$, $p < 0.0001$; $F2$ (1, 62) = 28.46, $MSE = 274$, $p < 0.0001$, indicating that more errors were made when C1 and C2 were separated by non-characters (24%) than by symbols (12%). The frequency × nature of mask interaction was also significant, $F1$ (1, 31) = 4.61, $MSE = 234$, $p < 0.05$; $F2$ (1, 62) = 4.12, $MSE = 274$, $p < 0.05$, indicating that the effect of nature of mask was stronger in high frequency pairs (16%) than in low frequency pairs (8%). No other effect approached significance (all *ps* > 0.05).

Discussion

Unlike Experiment 3, RB was observed only in error rates but not in reaction times in the present experiment. Although response latencies in repeated condition tended to be longer than that in unrepeated condition in Experiment 5, the repetition status fail to reach significance. It seems to be inconsistent with the results of Experiment 3 in which reliable RB was observed in reaction times data. It is unlikely that the category change in every trail, or a much wider range of stimuli set used in Experiment 5 minimized the RB effect because reliable RB could be observed in error rates, indicating that RB was not minimized.

It is speculated that since the number of trials in Experiment 5 (192 trials) was more than that in Experiment 3 (42 trails), and since both of the repeated items should be the correct exemplars in Experiment 5 (as well as Experiment 3), people may develop an identity guessing strategy or bias to give yes responses whenever the presented items were repeated. Specifically, they can get the correct responses without process the identities of the items in repeated condition, whereas the identities of two items should be processed in the unrepeated condition. As a consequence, the cost from RB might be canceled out by the benefit from the unnecessity of identity processing. Due to such limitation, the results found in Experiment 5 might not be so reliable. Such limitation would be remedied in Experiment 6 and the effect of frequency and nature of mask on RB will be discussed after Experiment 6.

Experiment 6

In order to prevent such identity guessing strategy or bias from developing, some filler trials, in which C1s were identical to C2s but both were not the exemplars of given categories, were added in Experiment 6. The number of the filler trails was equal to the number of trails containing repeated exemplars. Therefore, when repeated items were presented, the probability of that both items were the correct exemplars were equal to the probability of that both items were the incorrect exemplars. Most other aspects were the same as those in Experiment 5, except that participants were asked to respond only when both items were the exemplars of the corresponding categories. This would reduce the reaction time residue due to the decision making processes, and would also minimize the likelihood of that the observed results reflect the effect at the motor response level.

Method

Participants. Thirty-two undergraduate students from an introductory psychology course at the Chinese University of Hong Kong participated in this experiment. All of them were native Cantonese speakers with normal or corrected to normal vision. None of them had participated in the previous experiments.

Materials and Design. All of the aspects were the same as those in Experiment 5, except that this experiment added 64 filler trails in which both C1 and C2 were identical but both of them were not the exemplars of the corresponding categories.

Apparatus and Procedure. All aspects were the same as those in Experiment 5, except that participants were instructed to respond only when both items were correct exemplars, or they should not respond when there was one or no exemplar. The presentation duration of the ending pattern masks were shortened to 2000ms.

Results

Only the responses trails containing two targets were relevant to the analyses (the error rates for trails containing one target were 28%). Responses longer than 1500 ms or shorter than 100 ms (1.6%) were discarded from the analyses. The mean reaction times for correct responses and error rates were calculated across subjects and items separately and was subjected to a separate 2 (Frequency: high frequency pairs vs. low frequency pairs) $\times$ 2 (Repetition status: repeated vs. unrepeated) $\times$ 2 (Nature of mask: non-characters vs. symbols) ANOVA in that $F1$ refers to the subject-based analysis and $F2$ refers to the item-based analysis. Table 6 summarizes the mean reaction times for correct responses and error rates.

Table 6

Mean reaction times (ms) for correct responses and percentages of errors (in parentheses) in trails containing two targets of Experiment 6

	High frequency pairs		Low frequency pairs	
Conditions	non-characters	symbols	non-characters	symbols
Repeated	816 (36)	743 (16)	782 (34)	748 (12)
Unrepeated	740 (31)	686 (11)	801 (26)	746 (13)

Response latencies. The results revealed that the main effect of nature of mask was significant, *F1* (1, 31) = 8.1, *MSE* = 22927, $p < 0.005$; *F2* (1, 62) = 17.72, *MSE* = 13160, $p < 0.0001$, indicating that response latencies were longer when C1 and C2 were separated by non-characters (785 ms) than when C1 and C2 were separated by symbols (731 ms). Frequency was marginally significant, *F1* (1, 31) = 3.24, *MSE* = 10388, $p = 0.082$, *F2* (1, 62) = 3.99, *MSE* = 23406, $p = 0.05$. Response latencies for low frequency pairs (769 ms) tended to be longer than those for high frequency pairs (746 ms). The repetition status was also marginally significant, *F1* (1, 31) = 3.7, *MSE* = 14749, $p = 0064$; *F2* (1, 62) = 3.88, *MSE* = 10114, $p = 0.053$. Responses latencies in repeated condition (772 ms) tended to be longer than those in unrepeated condition (743 ms). The main effects of frequency and repetition status were qualified by the significant frequency × repetition status interaction, *F1* (1, 31) = 6.91, *MSE* = 13104, $p < 0.05$; *F2* (1, 62) = 3.93, *MSE* = 10114, $p = 0.052$, indicating that RB was found only in high frequency pairs (67 ms) but not in low frequency pairs (-9 ms). No other effect approached significance (all *ps* > 0.05).

Percentage of errors. The main effect of nature of mask was significant, *F1* (1, 31)

$= 58.82$, $MSE = 391$, $p < 0.0001$; $F2$ $(1, 62) = 69.32$, $MSE = 315$, $p < 0.0001$, indicating that there were more errors when C1s and C2s were separated by non-characters (32%) than when C1s and C2s were separated by symbols (13%). The main effect of repetition status was marginally significant in subject-based analysis, $F1$ $(1, 31) = 5.52$, $MSE = 367$, $p = 0.07$, and was significant in item-based analysis, $F2$ $(1, 62) = 5.02$, $MSE = 342$, $p < 0.05$, indicating that there were more errors in repeated condition (25%) than in unrepeated condition (20%). No other effect approached significance (all $ps > 0.05$).

Discussion

Experiment 6 revealed several interesting results. First, it successfully showed reliable RB in both reaction times and error rates, overcoming the possible limitation due to identity guessing strategy in Experiment 5. Together with the results in Experiments 2 and 3, RB in reaction times was consistently observed across different paradigms and different stimuli sets. These results suggest that in the cases the repeated items can be successfully reported, the processing of repeated items cannot be as successful as the processing of the unrepeated items.

Second, Experiments 5 and 6 failed to obtain a significant nature of mask × repetition interaction. This seems to imply that RB probably not due to the incorrectly binding of a repeatedly activated type with the old token, and the type-refractoriness hypothesis cannot be falsified. However, such interpretation should be taken in caution because of the marginal significant mask × repetition interaction was found in Experiment 5. In particular, the effect of RB observed in error rates tended to be larger when C1 and C2 were separated by non-characters than by symbols. Such results were similar to those found by Park and Kanwisher (1994a) in that only tendency of the interaction was observed. Therefore, it is still immature to give a definite conclusion on how RB was affected by the discriminability between C1 and C2.

Third, frequency interacted with repetition status in reaction times data such that RB was only found in high frequency pairs but not in low frequency pairs. Before the further discussion about such interaction, one speculation should be considered. That is the character frequency in Chinese tends to negatively correlate with the number of strokes. High frequency characters tends to be low in number of strokes, whereas low frequency characters tends to be high in number of strokes. That is also true for the materials used in Experiments 5 and 6. For C1s in unrepeated condition, the number of strokes for high frequency group (10.1) was lower than that for low frequency group (13.7), F (1, 62) = 11.61, MSE = 18.11, $p < 0.005$. For C2s, the number of strokes for high frequency group (10.4) was also lower than that for low frequency group (12.8), F (1, 62) = 5.87, MSE = 16.61, $p < 0.05$.

In order to test whether the main effect of frequency and the frequency × repetition status interaction observed in reaction times data was actually confounded by the effect due to number of strokes, a 2 (Frequency: high frequency vs. low frequency) × 2 (Repetition status: repeated vs. unrepeated) analysis of covariates (ANCOVA) was carried out on the item-based analysis with the number of strokes of C1s in unrepeated condition (C1 strokes) and the number of strokes of C2s (C2 strokes) as covariates in order to partial out their effects. It showed that the main effect of frequency was significant, F (1, 60) = 7.43, MSE = 22118, $p < 0.01$. The frequency × repetition status interaction was still marginally significant, F (1, 60) = 3.51, MSE = 10443, $p = 0.067$. More importantly, the effects C1 strokes and C2 strokes on the interaction were not significant, all Fs < 0.05, indicating that frequency effect and its interaction cannot be attributed to the difference in C1 strokes or C2 strokes. In addition, the pattern of results did not change for error rates when the C1 strokes and C2 strokes were statistically controlled. In sum, there is no evidence showing that number of strokes played influential impact on the overall results.

As mentioned earlier, Bavelier et al. (1994) attributed the reason why they did not observe significant interaction of frequency and repetition status, while others (e.g., Hochhaus & Mihura, 1992, cited in Bavelier et al., 1994) did, to different paradigms adopted in these two studies. However, the present experiment may provide an alternative account for such discrepancy. In the present experiment, significant frequency × repetition status interaction was only observed in reaction times but not in error rates, suggesting that frequency has little impact on error rates. It is possible that error rates itself are not sensitive enough to capture the frequency effect. Consistent with this claim, the main effect of frequency on error rates in present experiment and that in Bavelier et al, (1994, Experiment 2) was neither significant. Indeed, closer inspection of the results in Experiments 5, 6 and Bavelier et al's altogether consistently revealed that the effect size of RB in error rates tended to be larger in high frequency pairs relative to low frequency pairs. The RB effect size was 5 % in both Experiments 5 and 6 respectively for high frequency pairs, whereas it was 3% and 3.5% respectively for low frequency pairs. Similarly, the RB effect size was 35% and 29% for high and low frequency pairs respectively in Bavelier et al.'s experiment. Similar pattern showing RB effect tended to be smaller for low frequency pairs was also observed in Humphreys et al.'s (1988, Experiments 1-3). I will return to this issue in General Discussion.

Forth, Experiments 5 and 6 revealed a robust main effect of the nature of mask.

These findings are consistent with the study of attentional blink (AB) in that the effect size of attentional blink (AB) reduced as the similarity between the target and the item following the target decreased (Chun and Potter, 1995; Raymond, Shapiro, & Arnell, 1995). AB refers to a phenomenon that when two targets are embedded in an RSVP list, the detection of the second target is impaired when the second target is presented within about 400 ms from the first target (Raymond, Shaprio, & Arnell, 1992). AB differs from RB in that AB is a temporally suppressing of processing to all stimuli of the second targets regardless of whether the second targets are identical to the first targets or not, whereas, RB refers to a processing difficulty of the repeated items. However, like RB, AB is possible to be observed in two-item paradigm as demonstrated in Experiments 5 and 6. It is interesting to apply reaction times analyses and two-item paradigm on AB in the furture research.

General Discussion

A series of experiments examining the repetition effect of two briefly presented identical items were reported. Some important findings are summarized as follows. Experiment 1 demonstrated RB in a category counting task such that RSVP lists with repeated animal characters were more likely to be reported as containing only one animal character relative to lists with two unrepeated animal characters. Experiment 2 modified the category counting task to a category monitoring task, in which both reaction times and error rates can be collected, to test whether the processing of the successfully responded repeated items was the same as that of the unrepeated one. When the presentation rate was fast (i.e., 117 ms/item) response times to the second animal characters were longer, and error rates were higher, for RSVP lists containing repeated animal characters than lists containing two unrepeated animal characters. It indicates that even repeated items can be successfully responded, their processing is suffered from repetition deficit. However, when the presentation rate was relatively slow (i.e., 200 ms/item), response times were faster for repeated than unrepeated condition, and no difference was observed in error rates. Two-item paradigm was adopted in Experiment 3 and results revealed a similar pattern with those observed in Experiment 2. RB was only observed in shortest presentation duration (i.e., 70 ms) but not in a slightly longer presentation duration (i.e., 100 ms), whereas, repetition priming was observed in the longest presentation duration (i.e., 200 ms). The similarity of the results obtained in Experiments 2 and 3 was in line with the idea that RSVP and two-item paradigm capture the common aspect of RB. When the nature of task was changed to respond to C2 only (i.e., to indicate whether the second presented character was an animal character), RB changed to repetition priming in Experiment 4. These results suggest that the absolute duration of C1 alone is not a prominent factor in determining RB. Experiments 5 and 6 examined discriminability and frequency effects on RB. Experiment 6 revealed that RB was mainly found in high frequency pairs but not in low frequency pairs. Also, there is no strong evidence indicating that RB will be stronger when C1 and C2 were less discriminable. Based on these findings, some issues about RB, especially what happens to the second repeated item, are discussed.

The locus of RB: Encoding or retrieval failure?

RB was initially demonstrated in RSVP recall task, in which encoding, storage, retrieval and output operations are all included. The notion *Repetition Blindness* named by Kanwisher (1987) implies it is a phenomenon that happens at the encoding stage rather than at storage or retrieval stage. However, recently some researchers (e.g., Armstrong & Mewhort, 1995; Fagot & Pashler, 1995; Whittlesea, Dorken & Podrouzek, 1995; Whittlesea & Podrouzek, 1995) argued that RB is a misleading notion because this phenomenon happens at retrieval or output stages of operation.

Evidence against the idea that RB is due to encoding failure is mainly by showing the performance in repeated condition did not differ from that in unrepeated condition when the memory demand of the tasks were reduced. For example, Fagot and Pashler (1995) demonstrated a series of experiments arguing against RB is an on-line encoding phenomenon. In one of their experiments (Experiment 3), they presented two potential targets (e.g., *A* and *B*) followed by a sequentially presented items presented from left to right on the computer screen. Participants were required to indicate the location, identity or both of the targets embedded in the RSVP list. Results showed that the performance in the repeated condition (e.g., two *A*s, or two *B*s) was not statistically worse than that in unrepeated condition (e.g., *AB*, or *BA*) regardless of whether location, identities or both were required to be reported. In another experiment (Experiment 4), they changed the color of the second repeated items to red. Participants would either report which item in an RSVP list was red first and then recall all the items, or vice versa. Fagot and Pashler argued that if RB was due to encoding failure, the encoding problem should be independent of the order of report (i.e., whether red report first, or full report first) such that performance in red report should be poorer in repeated condition relative to unrepeated condition regardless of whether red report was performed first. Results revealed that no significant RB was observed regardless of whether red report was performed first.

Armstrong and Mewhort (1995) did not agree RB occurs at encoding stage either.

They reasoned that failure in reporting items needs not indicate that those items are not encoded, and these items can be reported if an appropriate situation is provided. They presented a probe which was one of the letter in an RSVP list as a cue and asked participants to report the target items, that was the item following the probe. For example, in the list J W C J B V X, participants had to report J when the probe was C. They hypothesized that if repetition blindness is an encoding problem and hence the repeated letter should not be encoded, then people will tend to report C2 less accurately in an experimental list with repeated items relative to a control list without repeated items, i.e. Z W C J B V X. If repetition blindness is a memory retrieval problem and the second repeated letter had really been encoded, then performance in repeated condition will not be different from that in unrepeated condition. Their results confirmed the later prediction.

These studies seem to provide evidence against RB is due to encoding failure. However, several considerations should be mentioned before concluding that RB *should not* be an encoding problem. First, considering the null effects obtained by Fagot and Pashler (1995), "none" of their results showed an opposite direction to RB[9] (see

---

[9] In Fagot and Pashler (1995) study, results indicating null effect of repetition showed that the values in unrepeated condition were all greater than those in repeated condition. In their Experiment 2, the proportion of trials in that targets were correctly located was 45.1 and 47.5 for repeated and unrepeated conditions, respectively. In their Experiment 3, proportion of trails that targets were correctly (a) located was 43.1 and 43.6, (b) identified was 57.5 and 65.0 and (c) both was 30.9 and 34.0, for repeated and unrepeated condition, respectively. In their experiment 4, when full report was performed first, the correct proportion of red report was 42.7 and 43.6 for repeated and unrepeated conditions, respectively; when red report performed first, the correct proportion of red report was 55.8 and 57.8 for repeated and unrepeated conditions, respectively. All of the differences were not statistically significant, but all were in the same direction. That is performance in unrepeated condition was not better than that in repeated condition.

Kanwisher et al., 1996 for other criticisms) . Such highly consistent direction across many experiments in Fagot and Pashler's studies was unlikely to be the results of chance. Second, the cued recall task used by Armstrong & Mewhort (1995) may overestimate performance in repeated condition. In fact, there is evidence showing that the presence of post-list cues can enhance performance on repetition detection of RSVP lists (Whittlesea & Podrouzek, 1995), and hence the RB may be canceled out by the effect of the post-list cues in Armstrong & Mewhort's study. Third, these studies only collected the error/correct rates as dependent variables. Experiments reported in the present study showed that it is sometimes less sensitive enough to show RB in error rates (e.g., Experiments 3 and 6). It is not clear whether such null effect could also be observed if these studies were modified to enable the collection of response times. Taking all of these together, evidence directly objecting that performance in repeated condition were different from that in unrepeated condition under in partial report was not strong.

Can RB be a storage problem? It is unlikely that RB is a storage problem because: First, the effect size of RB does not increase as memory load was increased by adding additional items in RSVP lists (Park and Kanwisher, 1994). Second, concurrent articulation, which is assumed to impair the memory rehearsal process in working memory (Besner, 1987; Besner, Davies, & Daniels, 1981), does not eliminate RB (Bavelier, 1994; Bavelier & Potter, 1992). Third, RB was observed in tasks where memory demand was relatively at minimum (e.g., Hochhaus & Johnston, 1996; Hochhaus & Marohn, 1991; Humphreys et al., 1988; Kanwisher et al., 1995; Luo & Caramazza, 1995). Finally, storage account for RB is difficult to explain the results in the present study, that is response times in repeated condition were longer than those in unrepeated condition when presentation rate was fast, but the opposite was true when presentation rate was slow. Therefore, available evidence does not support that RB happens at storage stage.

Can RB be a retrieval or output problem? The answer depends on how one defines RB. If RB is defined as the differences of recall performance between repeated and unrepeated condition, the operational definition adopted by most of RB literature (Bavelier, 1994; Bavelier & Potter, 1992; Kanwisher, 1987, 1991 Kanwisher & Potter, 1989; 1990), the answer is probably "yes" since recall task should involve retrieval or output operations, and indeed, there is evidence supporting that the retrieval of the C1 interfere the retrieval of the repeated items. For examples, Fagot and Pashler (1995) presented three items auditorally and then three other items visually. A report cue then appeared to indicate participants to report either all the items or only the visually presented items. In the repeated condition, C1 would be presented auditorally, whereas C2 would be presented visually. The effect of RB was much larger when all items were required to be reported relative to when only the visually presented items were required to be reported. In this case, the encoding of C2 was unlikely to be affected by the presence of C1 because the auditory prefix items were presented without time constraint. The RB observed in this experiment indicates that the retrieval of C1 may interfere the retrieval of C2 when they are identical. Thus, RB shown in tasks that involve retrieval operations, such as RSVP recall task, likely comprises the retrieval or output failure. In this case, the encoding and retrieval effects on RB are probably co-existent.

In other cases, RB has been shown in tasks that retrieval operations were not emphasized, such as Experiment 2 in the present study and all in the two-item paradigm (e.g., Hochhaus & Johnston, 1996; Hochhaus & Marohn, 1991; Humphreys et al., 1988; Kanwisher et al., 1995; Luo & Caramazza, 1995). Especially, RB was observed when only C2 have to be reported (e.g., Hochhaus & Marohn, 1991; Humphreys et al., 1988), or when only C2 have to be responded to (e.g., Experiment 2). RB in these studies was not likely to be due to retrieval failure under these conditions. Moreover, RB diminishes as the presentation rate becomes slower (Kanwisher, 1987; Park & Kanwisher, 1994a), it is unclear how the retrieval failure works in fast presentation rate, and does not work in slow presentation rate. RB in terms of response times observed in the present study by the on-line task further suggests that storage and retrieval failure are not the full account of RB.

In sum, there is evidence supporting the existent of both encoding failure and retrieval failure of the second repeated items. Whether RB involved encoding failure, retrieval failure or both is dependent on observing RB under what kind of tasks. It seems to be reasonable to conclude that RB effect originally demonstrated by Kanwisher (1987) might involve both encoding and retrieval failure since both encoding and retrieval operations are involved in the RSVP recall task. RB observed in the present study and that in two-item paradigm in which retrieval operation is relatively less emphasized seems to be due to encoding failure. Repetition deficit[10] observed in tasks in which encoding of C2 are unlikely to be impaired (e.g., Fagot & Pashler, 1995, Experiment 5) more likely reflects the failure at retrieval stage.

Type-token binding failure or type refractoriness?

---

[10] It seems to be not appropriate to use "blindness" since such phenomenon does not involve encoding failure.

Although type-token binding failure hypothesis proposed by Kanwisher (1987; Kanwisher et al., 1996; Park & Kanwisher, 1994a) does not, at least explicitly, state what is the processing of the repeated item involved when a type successfully bind with a token, Kanwisher et al. (1996) tended to regard RB as an all-or-none process: "Reports by the participants in our experiments raised the possibility that detection of second targets may be essentially an all-or-none process." (p. 1251). Thus, type-token binding failure hypothesis seems to assert that the processing of the repeated items which can be successfully responded to is essentially the same as the processing of the unrepeated items.

However, the present study consistently showed that response times for the repeated items were longer than those for unrepeated items, revealing that, in contrast to Kanwisher et al. (1996), RB is not an all-or-none phenomenon, in the sense that repeated items and unrepeated items are processed differently. Then, what is the difference? Why the repeated items need more time to be processed?

The reaction times RB can be accommodated by type refractoriness hypothesis in following way. When C2 falls within the refractory period, its visual information can be hold in the sensory store for a short period of time after the physical offset (Di Lollo & Dixon, 1988; Sperling, 1967). The processing of C2 either cannot start until the refractory period is over, or more activation is necessary to be accumulated for re-activation of the same type. As a consequence, the processing time of C2 will be longer due to the period of waiting the over of refractory period, or the period of waiting accumulation of more activation. If the visual information of C2 in sensory store decays and losses before the over of the refractory period, C2 will be lost in sight and hence more error rates are observed in the repeated condition.

Does this mean that type refractoriness hypothesis is a better account of RB than type-token binding failure hypothesis? However, Experiment 4 showed that C1 is necessary to be attended or reported for the occurrence of RB. It suggests that C1 have to be individuated as a distinctive token from C2 for the occurrence of RB, which is inconsistent with the prediction of type refractoriness hypothesis according to the reasoning of Luo and Caramazza (1995).

Therefore, type-token binding failure hypothesis and type refractoriness hypothesis alone is not enough to explain the whole phenomenon of RB. Type-token binding failure hypothesis does not state explicitly what the mechanism of the type-token binding is and it seems to regard type-token binding as an all-or-none process. The longer reaction times in repeated condition is more likely reflecting that the type-token binding processes in repeated condition are different from those in unrepeated condition. On the other hand, although type refractoriness hypothesis can capture the reaction times data found in the present study well, it is inconsistent with the findings that C1 is necessary to be attended/reported for the occurrence of RB.

As mentioned above in the discussion of Experiment, "type-token binding" is functionally similar to "the final step of supraliminal perception". Thus the idea that a refractory period is triggered by a supraliminal encoding according to Luo and Caramazza (1995) seems to be the same as the idea that a refractory period is triggered after type-token binding. Specifically, type-token binding failure hypothesis can be modified that a type cannot bind with another token within a certain period of time after the type-token binding of C1. If so, type-token binding failure hypothesis and type refractoriness hypothesis cannot be differentiated by observing the effect of whether C1 is necessary to be reported or not. Rather, the critical difference of these two hypotheses is on whether the type of C1 was activated at the moment of the onset of a repeated item. Further research should address whether the presence of a repeated item activate its type to show whether RB is the result of type-token binding failure or type refractory period.

One of the concerns about the refractory type of explanation of RB is that the effect of RB can observed even when C1 and C2 are intervened by four items or above (Kanwisher et. al., 1996; Luo & Caramazza, 1996; Park & Kanwisher, 1994a). Suppose an item is exposed for 100 ms, if RB is observe when C1 and C2 are intervened by four items, the refractory period lasts for at least 400 ms or above. Can the refractory period last for so long? Although there is evidence showing that inhibition process can last for up to 1000 ms or above in negative priming studies (Fox, 1996; Park & Kanwisher, 1994b; see Fox, 1995; May, Kane, & Hasher, 1995 for review of negative priming), previous studies on RB had mostly used recall task and hence the RB observed when C1 and C2 were intervened by many items may be probably due to retrieval failure. In addition, these studies had just collected error rates which cannot directly reflect what the second target happens. Further research should examine whether RB can survive when C1 and C2 are intervened by many items in the task that retrieval operation is at the minimum and response times to the second targets can be collected, such as the category monitoring task used in the present study.

Repetition priming and RB

In the present study, RB changed to repetition priming under two conditions. First, when the first occurrences of two items were not necessary to be responded to. Second, when the presentation rate became relatively slower (i.e., 200 ms/item), or when the presentation duration became relatively longer (i.e., 200 ms). In the first condition, C1 is not necessary to be responded to, whereas in the later condition, both C1 and C2 should be responded well. Though these two effects are also called repetition priming, they seem to be different in nature.

For the repetition priming observed in tasks in which C1 is not necessary to be responded to (e.g., Experiment 4), its nature may be similar to the repetition priming observed in masked repetition priming (Forster & Davis, 1984; Forster, Davis, Schoknecht, & Carter, 1987; Humphreys et al., 1988; Humphreys, Evett & Quinlan, 1990). Kanwisher (1987) argued that the prime and target in masked priming are not individuated as two separate tokens, and hence two stimuli are treated as one. When C1 should be individuated as an separate token from C2, RB will be observed. Similarly, Luo and Caramazza (1995; 1996) argued that repetition priming occurs because of the summation of activation of C1 and C2 when C1 is encoded subliminally. When C1 is encoded supraliminaly, it will induce a refractory period and RB will be observed when C2 falls within that period. The necessary condition for this kind of repetition priming is that C1 should be processed below the threshold of consciousness (i.e., a type does not bind with a token, or a subliminal perception).

Then, why both RB and repetition priming can be observed in the same exposure duration of C1 (e.g., Experiments 3 and 4)? It is probably that the threshold of C1 is not an absolute value. Its value may change according to the attention allocation, similar to the idea that threshold varies as a function of expectation proposed by Treisman (1960). In the task where C1 is necessary to be responded to, more attention should be allocated to C1, and hence its threshold is adjusted to be lower. However, in task where C1 is not necessary to be responded to, most of the attention can be allocated to C2, and hence the threshold of C1 is adjusted to be higher. This suggestion is also in-line with Kanwisher et al. (1995) who stated that RB critically depends on the attention allocation.

For the repetition priming observed in relatively slow presentation rate (and longer presentation duration), the benefit in the repeated condition seems to due to the fact that only one identity is necessary to be processed for the repeated pairs, whereas two identities are necessary to be processed for unrepeated pairs. In the repeated condition, when a stimulus is presented, a complete recognition process, from feature analysis to accessing the semantic information, is necessary to give a correct response. When the same item is presented again, now a complete recognition process can be replaced by a more rapid memory retrieval process (Logan, 1990). Rather than accessing to the semantic information in long term memory, the category of the repeated items can be achieved by accessing the information in working memory. This argument is consistent with the claim that there is a repetition-detection process to deal with the repeated items (Arbuthnott, 1996; Bentin & McCarthy, 1994), and the processing of repeated items, which is memory-based, is qualitatively different from the processing of unrepeated items, which is algorithmic-based (Logan, 1990).

It is interesting to note that if such repetition detection process also works in the fast presentation condition in which RB is observed, such as Experiments 2, 3 and 6 in the present study, the effect of RB might be underestimated. That is, although a repeated item was suffered from RB, it may also be benefical from the repetition detection process. The effect size of RB, therefore, may be minimized. If the benefit from the repetition detection process is over the cost of RB, it may expect that repetition priming, rather than RB is observed. The interaction that RB was only found in high frequency pairs but not in low frequency pairs in Experiment 6 is consistent with this prediction (see the section *Frequency Effect on RB*). Further research is necessary to show whether such repetition detection process also operates in a relatively fast presentation rate in which RB was induced, and whether RB was minimized by such process.

Frequency Effect on RB

RB was mainly observed in high frequency pairs in the present study (Experiment 6). There are three possibilities explaining such phenomenon. First, Experiments 5 and 6 showed that the processing of low frequency Chinese characters is slower than that of high frequency Chinese characters (see also, Liu, Wu, & Chou, 1996; Seidenberg, 1985). It is possible that the onset of the processing of C2 in low frequency pairs is before the offset of the processing of C1. As mentioned above, a complete processing of C1 (above threshold) is a necessary condition for the occurrence of RB, there should be no RB if C2 is processed before C1 reaching threshold.

Another possibility is due to the co-existent of two repetition effects. RB and repetition priming that low frequency pairs saved more processing time due to repetition detection process proposed above than high frequency pairs, and hence the cost of RB was compensated by the benefit from repetition detection in low frequency pairs. Indeed, Scarborough et al.(1977; see also Feutsel et al., 1983) observed that larger frequency effect was found in low frequency words in lexical decision task, indicating that the repetition detection process is more beneficial for low frequency words than for high frequency words. It is worthwhile to note that the idea of two repe.tition effects contributing to the processing of repeated items seems to be able to satisfactorily account for a wide range of empirical findings in the present study, including the RB and repetition priming in Experiments 2 and 3, and the frequency × repetition status interaction in Experiment 6.

The third possibility is that low frequency characters should be relatively unfamiliar and novel. Attention is generally assumed to seek for novelty (Johnston, Hawley, Plewe, Elliott, & DeWitt, 1990) and since RB is sensitive to attentional factors (Kanwisher, 1991; Kanwisher et al., 1995), the effect sizes of RB should diminished in low frequency characters. Further research should examine these hypotheses.

Methodological concerns

The present study successfully applies the reaction times analyses on RB investigation. In particular, some effects were only observed in reaction times but not in error rates (e.g., Experiments 3, 4, & 6). It raises the possibility of that error rates alone may not really capture the full story of RB. Given that the category monitoring task can provide meaningful and interpretable results in terms of reaction time, it is suggested that future research on RB (or even AB) should paid more attention on reaction time data in order to reflect the processing of the successfully responded repeated items.

Another concern is that previous research of RB mainly adopted tasks that do not emphasized the use of semantic information. As Bavelier (1994; Bavelier & Potter, 1992) showed that task emphasis can alter the effect of RB in that RB occurs only when the task emphasizes on the right aspect (i.e., visual code, or phonological code). Similarly, Kanwisher et al. (1995) showed that RB occurs only when the task emphasizes on the right dimension (i.e., symbol or color). The category counting/monitoring task adopted in the present study provides a task which emphasizes on the semantic code for RB research. It is interesting to examine whether some types of RB can survive in this task, or other types of RB which is not so reliable can give consistent results in this task.

For example, phonological RB has been widely investigated by the RSVP recall tasks (Bavelier & Potter, 1992; Bavelier et al., 1994) and the past research showed that it is a robust phenomenon such that the effect occurs even when C1 and C2 shared a certain amount of syllables, rather than shared the complete phonological information (Bavelier et al., 1994). Since the recall task should induce high memory demand, and phonological code is used for rehearsal in working memory (Baddeley, 1986; Conrad, 1964), it may encourage participants to encode stimuli phonologically in order to use the phonological code for rehearsal. Thus, it is important to know that whether phonological RB can survive in tasks such as the category monitoring task in which memory demand is low and phonological encoding is not emphasized. Unfortunately, no such empirical data is available up to now[11].

Similarly, semantic RB has also widely been investigated by the RSVP recall tasks.

---

[11] One more question should be addressed before concluding phonological RB is a general or even a universal phenomenon. That is the role of phonology in word recognition in different writing systems. Although recently more and more evidence suggest that phonological information is activated very early even before lexical access in recognizing alphabetic English (Luo, 1996; Perfetti & Bell, 1991; Perfetti, Bell, & Delanay, 1988; Rayner et al., 1995; Tzelgov, Henik, Sneg & Baruch, 1996; Van Orden, 1987; Van Orden, Johnston & Halle, 1988), such conclusion seems to be too early to generalize to logographic writing systems such as Chinese. Instead, some evidence suggest that phonology is activated lately in Chinese after lexical access (Chen, Flores d'Acracis & Cheung, 1995; Liu, Wu, & Chou, 1996; Perfetti and Zhang, 1991;See Chen, 1992, 1996; Hung and Tzang, 1981 for reviews of Chinese). Since alphabetic English is the only language that has been used to investigate phonological RB, it is not clear whether phonological RB can also be generalized to other language other than alphabetic English such as logographic Chinese.

Unlike phonological RB, semantic RB is a relatively weak phenomenon. For examples, the RB effect size of morphologically related pairs (e.g. *edit-edited*) was found to be virtually the same as that of morphologically unrelated control pairs (e.g. *wand-wander*) (Bavelier et al. 1994; Kanwisher & Potter, 1990). RB can neither be found between irregular verb pairs which is orthographically dissimilar such as *take* and *took* (Bavelier et al., 1994), synonym word pairs such as *autumn* and *fall* (Kanwisher & Potter, 1990), nor cross language (Spanish-English) words pairs with identical meaning such as *sobrino* and *nephew* (Altarriba & Soltano, 1996; but see MacKay et al., 1996 for criticisms). Furthermore, when sentences that can produce RB were heard by subjects in compressed speech version, Kanwisher and Potter (1989), did not observe repetition deafness. These evidences seem to suggest that RB is a modality specific phenomenon and its locus is at somewhere lower than semantic. On the other hand, MacKay and M. Miller (1994) observed reliable RB when C1 and C2 are semantically identical cross language (Spanish-English) words (e.g. *gusta-like*) in a faster presentation rate. M. Miller and MacKay (1994) also observed repetition deafness when compressed speech with unrelated items, but not with sentences, was presented in faster rate. The category monitoring task which emphasizes the use of semantic information may be useful to resolve such discrepancy.

Conclusions

As RB research generally ignored what happens to the repeated items which can be successfully responded in an RB induced condition, the present study provides some empricial findings showing that the processing time of successfully responded repeated item was longer than that of successfully responded unrepeated item, implying that RB is not just an all-or-none phenomenon. Such processing difficulty of repeated item is true in different experimental procedures such as the RSVP task in Experiment 2 and the two-item task in Experiments 3 and 6. In addition, RB observed in the present study unlikely involves storage or retrieval problem such that (a) the RB was observed in tasks in which storage and retrieval operations were not emphasized and were relatively minimal, (b) the RB changed to repetition priming in relatively slower presentation rates or longer presentation durations. The present study also indicates that error rates alone may sometimes less sensitive to capture the repetition effects, suggesting that the reaction times to the repeated items should not be ignored.

References

Abram, L., Dyer, J. R., & MacKay, D. G. (1996). Repetition blindness interacts with syntactic grouping in rapidly presented sentences. *Psychological Science, 7,* 100-104.

Altarriba, J., & Mathis, M. (1997). Conceptual and lexical development in second language acquisition. *Journal of Memory and Language, 36,* 550-568.

Altarriba, J., & Soltano, E. G. (1996). Repetition blindness and bilingual memory: Token individuation for translation equivalents. *Memory & Cognition, 24,* 700-711.

Arbuthnott. K. D. (1996). To repeat or not to repeat: Repetition facilitation and inhibition in sequential retrieval. *Journal of Experimental Psychology: General, 125,* 261-283.

Armstrong, I. T., & Mewhort, D. J. K. (1995). Repetition deficit in Rapid-Serial-Visual-Presentation displays: Encoding failure or retrieval failure? *Journal of Experimental: Human Perception and Performance, 21,* 1044-1052.

Baddeley, A. D. (1986). *Working memory.* Oxford, England: Clarendon.

Bavelier, D. (1994). Repetition blindness between visually different items: the case of pictures and words. *Cognition, 51,* 199-236.

Bavelier, D., & Potter, M. C. (1992). Visual and phonological codes in repetition blindness. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 134-147.

Bavelier, D., Prasada, S., & Segui, J. (1994). Repetition blindness between words: Nature of the orthographic and phonological representations involved. *Journal of Experimental Psychology: Learning, Memory and Cognition, 20,* 1437-1455.

Bentin, S., & McCarthy, G. (1994). The effects of immediate stimulus repetition on reaction time and event-related potentials in tasks of different complexity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 130-149.

Besner, D. (1987). Phonology, lexical access in reading, and articulatory suppression: A critical review. *Quarterly Journal of Experimental Psychology, 39A,* 467-478.

Besner, D., Davies, J., & Daniels, S. (1981). Reading for meaning: The effect of concurrent articulation. *Quarterly Journal of Experimental Psychology, 33A,* 415-438.

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception & Performance, 21,* 109-127.

Chen, H. C. (1992). Reading comprehension in Chinese: Implications from character reading times. In H. C. Chen and O. J. L. Tzeng (Eds)., *Language processing in Chinese,* Amsterdam, Netherlands: North-Holland.

Chen, H.-C. (1996). Chinese reading and comprehension: A cognitive psychology perspective. In M. H. Bond (Ed.) *The handbook of Chinese psychology* (pp. 43-62). Hong Kong: Oxford University Press.

Chen, H. C., Flores d'Acracis, G. B., & Cheung, S. L. (1995). Orthographic and Phonological Activation in Recognizing Chinese Characters. *Psychological Research, 58,* 144-153.

Chen, H.-C., and Juola, J. F. (1982). Dimensions of lexical coding in Chinese and English, *Memory and Cognition, 10,* 216-224.

Conrad, R. (1964). Acoustic confusion in immediate memory. *British Journal of*

Psychology, 55, 75-84.

Crowder, R. G., & Melton, A. W. (1965). The Ranschburg phenomenon: Failure of immediate recall correlated with repetition of elements within a stimulus. *Psychonomic Science, 2,* 295-296.

Di Lollo. V., & Dixon, P. (1988). Two forms of persistence in visual information processing. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 671-681.

Downing. P., & Kanwisher, N. (1995). Types and tokens unscathed: A reply to Whittlesea, Dorken, and Podrouzek (1995) and Whittlesea and Podrouzek (1995). *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 1698-1702.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General, 113,* 501-517.

Evett, L. J., & Humphreys, G. W. (1981). The use of abstract graphemic information in lexical access. *Quarterly Journal of Experimental Psychology, 33A,* 325-350.

Fagot, C., & Pashler, H., (1995). Repetition blindness: Perception or memory failure? *Journal of Experimental Psychology: Human Perception and Performance, 21,* 275-292.

Feustel, T. C., Shiffrin, R. M., & Salasso, A. (1983). Episodic and lexical contributions to the repetition effect in word identification. *Journal of Experimental Psychology: General, 112,* 309-346.

Fleming, K. K. (1993). Phonological mediated priming in spoken and printed word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 272-284.

Forbach, G. B., Stanners, R. M., & Hochhaus, L. (1974). Repetition and practice effects in a lexical decision task. *Memory & Cognition, 2,* 337-339.

Forster, K. I. (1987). Form-priming with masked primes: The best match hypothesis. In M. Coltheart (Ed.), *Attention and performance XII* (pp. 127-146). Hillsdal, NJ: Erlbaum.

Forster, K. I., & Davis, C. W. (1984). Repetition priming and frequency attention in lexical access. *Journal of Experimental Psychology: Learning, Memory and Cognition, 10,* 680-698.

Forster, K. I., Davis, C. W., Schoknecht, C., & Carter, R. (1987). Masked priming with graphemically related forms: Repetition or activation? *Quarterly Journal of Experimental Psychology, 39A,* 211-251.

Fox, E. (1995). Negative priming from ignored distracters in visual selection: A review. *Psychonomic Bulletin & Review, 2,* 145-173.

Fox. E. (1996). Cross-language priming from ignored words: Evidence for a common representational system in bilinguals. *Journal of Memory and Language, 35,* 353-370.

Frost, R., Katz, L., and Bentin, S. (1987). Strategies for visual word recognition and orthographic depth: A multilingual comparison. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 104-115.

Gordon, R. D., & Irwin, D. (1996). What's in an object file? Evidence from priming studies. *Perception & Psychophysics, 58,* 1260-1277.

Grainger, J., & Ferrand, L. (1996). Masked orthographic and phonological priming in visual word recognition and naming: Cross-task comparisons. *Journal of Memory and Language, 35,* 623-647.

Hochhaus, L., & Marohn, K. M. (1991). Repetition blindness depends on perceptual capture and token individuation failure. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 422-432.

Hochhaus, L., & Johnston, J. C. (1996). Perceptual Repetition Blindness Effects. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 355-366.

Hong Kong Education Department. (1986). *Frequency count of Chinese words used in Hong Kong secondary school reading materials.* Hong Kong: Hong Kong Government Press.

Humphreys, G. W., Besner, D., & Quinlan, P. T. (1988). Event perception and word repetition effect. *Journal of Experimental Psychology: General, 117,* 51-67.

Hung, D. L., and Tzeng, O. J. L. (1981). Orthographic variations and visual information processing. *Psychological Bulletin, 90,* 377-414.

Inhoff, A.W., & Liu, W. (in press). The range of effective vision during the reading of Chinese sentences. In H.-C. Chen (Ed.) *The cognitive processing of Chinese and related Asian languages.* Hong Kong: Chinese University Press.

Jahnke, J. C. (1969). The Ranschburg effect. *Psychological Review, 76,* 592-605.

Jared, D. (1997). Spelling-sound consistency affects the naming of high-frequency words. *Journal of Memory of Language, 36,* 505-529.

Jared, D., & Seidenberg, M. S. (1991). Does word identification proceed from spelling to sound to meaning? *Journal of Experimental Psychology: General, 120,* 358-394.

Johnston, W. A., Hawley, K. J., Plewe, S. H., Elliott, J. M. G., & DeWitt, M. J. (1990). Attention capture by novel stimuli. *Journal of Experimental Psychology:*

General, 119, 397-441.

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology, 24,* 175-219.

Kanwisher, N. (1987). Repletion blindness: Type recognition without token individuation. *Cognition, 27,* 117-143.

Kanwisher, N., Driver, J., & MacHado, L. (1995). Spatial repetition blindness is modulated by selective attention to color or shape. *Cognitive Psychology, 29,* 303-337.

Kanwisher, N., & Potter, M. C. (1989). Repetition blindness: The effects of stimulus modality and spatial displacement. *Memory and Cognition, 17,* 117-124.

Kanwisher, N., & Potter, M. C. (1990). Repetition blindness: Levels of processing. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 30-47.

Kanwisher, N., Kim, J. W., & Wickens, T. D. (1996). Signal detection analyses of repetition blindness. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 1249-1260.

Liu, I. M., Wu, J. T., & Chou, T. L. (1996). Encoding operation and transcoding as the major loci of the frequency Effect. *Cognition, 59,* 149-168.

Liu, Y. (1996). Queueing networking modeling in elementary mental processes. *Psychological Review, 103,* 116-136.

Logan, G. D. (1990). Repetition priming and automaticity: Common underlying mechanisms? *Cognitive Psychology, 22,* 1-35.

Luo, C. R. (1996). How is word meaning accessed in reading? Evidence from the phonologically mediated interference effect. *Journal of Experimental*

Psychology: Learning, Memory, and Cognition, 22, 883-895.

Luo, C. R. and Caramazza, A. (1995). Repetition Blindness under minimum memory load: Effects of spatial and temporal proximity and the encoding effectiveness of the first item. *Perception & Psychophysics, 57,* 1053-1064.

Luo, C. R., & Caramazza, A. (1996). Temporal and spatial repetition blindness: Effects of presentation mode and repetition lag on the perception of repeated items. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 95-113.

May, C. P., Kane, M. J., & Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin, 118,* 35-54.

MacKay, D. G., Abram, L., Pedroza, M. J., & M. Miller D. (1996). Cross-language facilitation, semantic blindness, and the relation between language and memory: A reply to Altarriba and Soltano. *Memory & Cognition, 24,* 712-718.

MacKay, D. G., & Miller. M. D. (1994). Semantic blindness: Repeated concepts are difficult to encode and recall under time pressure. *Psychological Science, 5,* 52-55.

Miller, J. O. (1993). A queue-series model for reaction time, with discrete-stage and continuous-flow models as special cases, *Psychological Review, 100,* 702-715.

Miller, M. D., & MacKay, D. G. (1994). Repetition deafness: Repeated words in computer-compressed speech are difficult to encode and recall. *Psychological Science, 5,* 47-51.

Park, J., & Kanwisher, N. (1994a). Determinants of repetition blindness. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 500-519.

Park. J., & Kanwisher, N. (1994b). Negative priming for spatial locations: Identity mismatching, not distracter inhibition. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 613-623.

Perfetti, C. A., Bell, L. C., & Delaney, S. M. (1988). Automatic (Prelexical) Phonetic Activation in Silent Word Reading: Evidence from Backward Masking. *Journal of Memory Language, 27,* 59-70.

Perfetti, C. a., & Bell, L. C. (1991). Phonemic activation during the first 40 ms of word identification: Evidence from backward masking and priming. *Journal of Memory and Language, 30,* 473-485.

Perfetti, C. A., & Zhang, S. (1991). Phonemic processes in reading Chinese words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 633-643.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1995). Similarity determines the attentional blink. *Journal of Experimental Psychology: Human Perception & Performance, 21,* 653-662.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception & Performance, 18,* 849-860.

Rayner, K., Sereno, S. C., Lesch, M. F., and Pollatsek, A. (1995). Phonological codes are automatically activated during reading: Evidence from an eye movement priming paradigm. *Psychological Science, 6,* 26-32

Rayner, K., and Pollatsek, A. (1989). *The Psychology of Reading*. Englewood Cliffs, NJ: Prentice Hall.

Scarborough, D. L., Cortese, C., & Scarborough, H. S. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology:*

Human Perception and Performance, 3, 1-17.

Scarborough, D. L., Gerard, L., & Cortese, C. (1979). Accessing lexical memory: The transfer of word repetition effects across task and modality. *Memory & Cognition, 7,* 3-12.

Scarborough, D. L., Gerard, L., & Cortese, C. (1979). Independence of lexical accessing bilingual word recognition. *Journal of Verbal Learning and Verbal Behavior, 23,* 84-99.

Segui, J., & Grainger, J. (1990). Priming word recognition with orthographic neighbors: Effects of relative prime-target frequency. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 65-76.

Seidenberg, M. S. (1985). The time course of phonological code activation in two writing system. *Cognition, 19,* 1-30.

Simpson, G. B., and Kang, H. (1994). The flexible use of phonological information in word recognition in Korean. *Journal of Memory of Language, 33,* 319-331.

Sperling, G. (1967). Successive approximations to a model for short-term memory. *Acta Psychologica, 27,* 285-292.

Treisman, A. M. (1960). Contextual cues in encoding listening. *Quarterly Journal of Experimental Psychology, 12*, 242-248.

Treisman, A. (1988). Features and objects: The fourteenth Bartlett Memorial Lecture. *Quarterly Journal of Experimental Psychology, 40A,* 201-237.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12,* 97-136.

Tzelgov, J., Henik, A., Sneg,, R., & Baruch, O. (1996). Unintentional word reading via the phonological route: The Stroop effect with cross-script homophones.

Journal of Experimental Psychology: Learning, Memory, and Cognition, 22, 336-349.

Van Order, G. C. (1987). A ROWS is a ROSE: Spelling, sound and reading. *Memory and Cognition, 15,* 181-198.

Van Orden, G. C., Johnston, J. C., & Hale, B. L. (1988). Word Identification in Reading Proceeds From Spelling to Sound to Meaning. *Journal of Experiment Psychology: Learning, Memory, and Cognition, 14,* 371-386.

Whittlesea, B. W. A., Dorken, M. D., & Podrouzek, K. W. (1995). Repeated events in rapid lists: Part 1. Encoding and representation. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21,* 1670-1688.

Whittlesea, B. W. A., & Podrouzek, K. W. (1995). Repeated events in rapid lists: Part 2. Remembering repetition. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21,* 1688-1697.

Appendix A

Materials Used in Experiment 3 and 4

Note: C1 = first critical character; C2 = second critical character

C2 and C1 in repeated condition	C1 in unrepeated condition	C2 for trails containing one animal character	C1 for trials containing one animal character
狐	蚊	燕	蟻
猿	鯊	蛾	鰻
鴨	貓	鶯	兔
虎	蛇	蜂	騾
蝦	狼	狸	狒
馬	象	鱷	蜆
鷹	蟬	龜	蚤
蛙	猴	鯨	驢
狗	魚	鵝	鱔
豬	雞	蠅	鶴
蟹	鴿	蝶	豚
獅	鹿	猩	牛
鼠	熊	犬	羊
雁	豹	鳥	蚌

Appendix B

Materials Used in Experiments 5 and 6

Note: C1 = first critical character; C2 = second critical character

Category	C1 in repeated condition and C2 in trails containing two animal characters	C1 in unrepeated condition
	High-frequency exemplars	
中國朝代	漢	唐
文具	筆	紙
生物	蜂	熊
生物	狗	鳥
生物	象	馬
交通工具	車	船
身體部份	背	腰
身體部份	肩	耳
身體部份	掌	鼻
身體部份	手	足
身體部份	髮	臉
身體部份	腦	膚
味道	苦	甜
固體	石	木
姓氏	張	何
姓氏	周	李
姓氏	梁	陳
計時工具	鐘	錶
食物	飯	菜
時間	月	日
情緒	歡	喜
液體	茶	湯
植物部份	根	花
貴重物品	玉	金
種族	蒙	藏
數字	五	十
數字	九	八
樂器	鼓	琴
親戚	姐	姊
營養食品	麥	奶
顏色	黑	綠
顏色	紅	黃

Appendix B (*Continued*)

Category	C1 in repeated condition and C2 in trails containing two animal characters	C1 in unrepeated condition
	Low frequency exemplars	
生物	狐	蚤
生物	猿	蛙
武器	鞭	棍
用具	刷	梳
武器	槍	劍
重量單位	噸	磅
身體部份	腹	臀
身體部份	肝	肘
生物	龜	鵝
生物	蝦	鴿
親戚	姪	姨
親戚	婿	媳
生物	虱	狒
食物	蒜	蔥
生物	兔	豹
水果	桃	蕉
生物	豚	蝶
生物	蠅	鯨
食物	菇	茄
花朵	菊	梅
生物	蟹	鶴
生物	蜆	猩
生物	鷹	鱷
食物	粥	麵
水果	梨	蘋
生物	鹿	騾
生物	蛾	雀
生物	獅	雁
身體部份	唇	腸
身體部份	膝	膊
食物	粟	椒
食物	薯	餅